Tomato and Tuna: A Test for Language-Free Assessment of Action Understanding

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Objective: We introduce a novel test that allows pictorial, nonverbal assessment of action understanding.

Background: Focusing on action goals and the sequential nature of actions, the "Tomato and Tuna Test" tests whether exposure to the accomplished goal of an action is sufficient to infer the preceding action. This aspect has rarely been addressed in conventional paradigms.

Methods: We used the Tomato and Tuna Test in conjunction with another task, the Kissing and Dancing Test, to detect action understanding deficits in 11 patients (mean age 72 ± 6 years) with chronic brain lesions ± aphasia. We compared their performance to an age- and education-matched control group and to 15 young controls (mean age 24 ± 3 years). To investigate the influence of language deficits on test performance, we compared the scores of our patients with and without aphasia.

Results: Our patients were less accurate than the matched controls on the Tomato and Tuna Test, though not slower. The Kissing and Dancing Test did not differentiate between patients and matched controls. Young controls performed better than patients on both tests.

Conclusions: We found no performance differences between our aphasic and nonaphasic patients, confirming our assumption that both tests measure action understanding without requiring intact language abilities. We recommend the "Tomato and Tuna Test" as a new nonverbal measure of action understanding that can reveal subtle deficits.

Key Words: action goal, action recognition, nonverbal test, mirror neuron system, aphasia

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The TTT test stimuli can be obtained freely at http://www.amorydanek.de.

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Reader Benefit: This article introduces a new testing tool for nonverbal assessment of action understanding that can reveal subtle deficits in brain-damaged patients.

KDT = Kissing and Dancing Test; **TTT** = Tomato and Tuna Test.

Understanding the actions of others is a fundamental human ability, yet its working mechanisms are still not completely understood. In this study we examine action understanding in terms of how people infer the meaning of goal-directed actions in daily life. We present a new test, the "Tomato and Tuna Test" (TTT), which emphasizes 2 aspects of action understanding that are often neglected in conventional paradigms: action goals and the sequential nature of actions.

As the defining feature of any intentional action, goals have the power to trigger complex action programs (Ach, 1910; Hommel and Nattkemper, 2011). Particularly in functional imaging research, action tasks are often reduced to simple grasping movements, with no goal beyond reaching for an object (Gazzola and Keysers, 2009; Molnar-Szakacs et al, 2005; Van Overwalle and Baetens, 2009). Such studies allow only very limited inferences to be drawn about people's ability to understand an action in its complete nature, that is, sequentially directed to an intended goal (Hommel and Nattkemper, 2011).

In recent years, knowledge has been growing fast about the abilities to understand action goals as well as to infer other people's intentions, thanks in part to the discovery of a so-called "mirror neuron system" in monkeys and its analog in humans (Rizzolatti and Sinigaglia, 2010; Van Overwalle and Baetens, 2009). With the common coding principle, Prinz (1997) proposed a possible working mechanism for action understanding. He claimed that the visual representation of an observed action is mapped onto the motor representation of that action, and that this mapping allows the observer to infer the intention of the agent (direct matching). As a neural correlate of direct matching, Rizzolatti et al (2001) proposed the hypothetical mirror neuron system. This view has been challenged and widely discussed critically, with others suggesting involvement of inferential, perceptual, and memory-based mechanisms in addition to simple matching (Decety and Grèzes, 1999; Hickok, 2009; Kilner, 2011). Yet, brain regions supplied by the middle cerebral artery have consistently been identified as underlying the human ability to understand actions (Van Overwalle and Baetens, 2009).

While imaging research has succeeded in identifying the neural correlates of action understanding in healthy young adults (Van Overwalle and Baetens, 2009), studies are sparse in patients with lesions in these regions. One reason for the small number of studies investigating deficits may be the lack of suitable tests. We see 2 major limitations with existing tests. The most incapacitating deficit caused by left hemisphere lesions is aphasia, which can pose serious obstacles for testing. Likewise, testing can be hindered by apraxia, which is also most often caused by left hemisphere lesions.

We therefore developed a new test for action understanding that patients can complete without needing to be able to read and speak. The test focuses on both action goals and the sequential, logical order in which actions must be performed to reach these goals. Our design for the TTT necessitated the creation and representation of hierarchically structured action plans (Jeannerod, 1994). We devised a set of stimuli (see Figure 2 for an example) consisting of goal-directed actions of daily life, with the goals and the preceding actions depicted in separate images. The TTT, therefore, tackles participants' ability to represent mentally the correct temporal sequence of steps needed to reach an action goal.

Action understanding does not necessarily rely on the ability to describe the action verbally (Negri et al, 2007; Saygin et al, 2004). Thus, action understanding (conceptual knowledge about an action) can dissociate from language understanding (lexical knowledge about an action) (Rumiati et al, 2010).

There is further evidence that actions can be understood without retrieving lexical knowledge (eg, tip-of-the-tongue phenomena), as thoroughly discussed by Tranel et al (2003). But most existing action understanding tasks require intact language abilities. For example, Fiez and Tranel (1997) were the first to create a standardized set of tasks to investigate action understanding, with the aim of implementing tasks that did not specifically require lexical retrieval; however, all of Fiez and Tranel's tasks still drew strongly on language because participants were asked either to name or to rate action pictures on the basis of their properties (eg, "Which action would make the loudest noise?"). These stimuli cannot be used for patients who have severe language impairments.

In the study reported here, our aims were to test the sensitivity of the TTT in detecting possible action understanding deficits in patients with brain lesions in the areas believed to serve action understanding, and to compare the TTT to an existing test of action understanding, the Kissing and Dancing Test (KDT) (Bak and Hodges, 2003). The KDT has been shown to be diagnostic for frontotemporal dementia (Bak and Hodges, 2003) and motor neuron disease (Bak and Hodges, 2004).

Although both the TTT and the KDT investigate action understanding, they tap quite different aspects of actions. The KDT asks participants to find a match between 2 actions via the context in which they regularly occur, while the TTT explicitly focuses on the sequential nature of actions leading to a depicted goal.

We gave the TTT and the KDT to 3 groups of people. One group was patients with acquired permanent brain lesions, most caused by strokes affecting the middle cerebral artery. The territory of this artery comprises most of the regions thought to be part of the analog human mirror neuron system (Rizzolatti and Craighero, 2004). Of our 11 patients, 7 had aphasia and 4 did not. Our 2 other study groups were controls: a group of older people, age- and education-matched to the patients, and a group of young people with a mean age in their mid-20s.

As we had developed the TTT to allow testing without any language confounds, our inclusion of patients with and without aphasia offered us the possibility of confirming that the TTT could be given successfully without participants needing to use language. Because language deficits should not influence test performance, we expected to find no differences in performance between our aphasic and nonaphasic patients.

METHODS

Participants

We studied a total of 37 patients and controls. We recruited the patients at the Rehabilitation Unit of the Ospedali Riuniti in Trieste, Italy. The hospital's neuropsychologist routinely evaluates the patients in this Unit. For our purposes, the crucial assessments were the Token Test from the Italian version of the Aachen Aphasia Test (Luzzatti et al, 1994), to assess the patients' language understanding; the Trail Making Test Parts A and B (Tombaugh, 2004), to control for deficits in attention; and the Object Decision subtest from the Visual Object and Space Perception Battery (Warrington and James, 1991), to control for deficits in object recognition.

The neuropsychologist referred patients to us if they had undergone a neuropsychological evaluation within the past year (patients who had suffered their stroke >1 year earlier had returned to the neuropsychologist for a follow-up assessment) and if they met these inclusion criteria: age 50 to 85 years, at least 5 years of formal education, ability to understand test instructions after practice trials, and a history of a single cerebrovascular accident (either an ischemic or a hemorrhagic stroke), suffered at least 2 months earlier. The patients' handedness did not matter to the study.

A neuroradiologist who was blind to the study's hypotheses reviewed the patients' computed tomography scans to identify the lesioned areas and then drew them as regions of interest on the normalized Montreal Neurological Institute template using the program MRIcro (Rorden and Brett, 2000). To avoid confounds caused by vision impairment, we excluded patients from the study if they had lesions to the posterior (occipital) regions.

Of the 11 patients who fulfilled all the study criteria, 7 had a neuropsychologically confirmed diagnosis of aphasia and 4 did not have aphasia. Tables 1 and 2 show the patients' demographic and neurologic profiles.

We recruited 2 groups of healthy controls through a participant database used regularly by researchers at the Scuola Internazionale Superiore di Studi Avanzati, Trieste. The "old" control group had 11 people who scored at least 24/30 (mean score 28.20; standard deviation [SD] 1.60) when they took the Mini-Mental State Examination (Folstein et al, 1975) during the experimental session. We then age- and education-matched these controls to our 11 patients. The "young" control group had 15 people with an average age of 24 years.

Table 3 summarizes the patients' and controls' sex, age, and education.

All participants gave informed consent before starting the study. Data were collected in accordance with the ethical standards of the 1964 Declaration of Helsinki. The study protocol was approved by the Scuola Internazionale Superiore di Studi Avanzati Institutional Review Board.

Tests of Action Understanding

KDT

We gave our participants 33 stimulus triplets from the 52-item KDT (Bak and Hodges, 2003). This test was designed to measure conceptual knowledge for actions. Each stimulus triplet comprises a presented action, a target action, and a distractor. Appendix 1 lists the KDT stimulus triplets that we used in our study.

The KDT is printed in a small paper booklet that is shown to the participants. In each trial, participants look at a set of 3 action drawings. At the top center of each triplet is a framed drawing of a presented action. In the example in Figure 1, the presented action is a hand writing with a fountain pen. Aligned horizontally beneath the framed presented action are 2 drawings, a target action (here, a hand typing) and a distractor (a hand stirring with a spoon in a teacup). Sometimes the target drawing is on the left, and sometimes on the right. Participants are asked to point at the drawing that most closely matches the presented action.

TTT

As described, we developed the TTT to study action understanding by asking participants to infer the preceding action from the action goal. The reverse order of this task—first the goal, then the action—presents a higher level of difficulty than the KDT, might require more frontal involvement, and might reveal more subtle deficits.

Unlike the KDT, the TTT is computerized. Like the KDT, the TTT uses images of stimulus triplets. Each triplet comprises an action goal, a target (a preceding action), and a distractor. Appendix 2 shows the 26 TTT

TABLE 1. Demographic and Illness-Related Data for 11 Patients with Chronic Brain Lesions from a Stroke

Patient Number and Sex	Age (Years)	Education (Years)	Type of Stroke	Sites Affected by Lesion	Brodmann Areas Involved in Lesion	Time Since Stroke
1 Man	69	8	Hemorrhagic	Left basal ganglia, bilateral cortical atrophy most evident in frontal areas	20, 37; mainly subcortical	3 years
2 Woman	71	8	Ischemic	Large hypodense frontoparietal lesion (cortical and subcortical) and territory of the middle cerebral artery (all left)	1, 2, 3, 4, 7, 19, 21, 22, 37, 39, 40, 41, 42, 43; subcortical	3 months
3 Woman	75	5	Ischemic	Striatum, pallidum, internal and external capsule, and subcortical white matter deep frontal (all left)	11, 20, 25, 47; mainly subcortical	1 year
4 Man	77	5	Ischemic	Large hypodensity in the right temporal-frontal-parietal areas (involving about 2/3 of the territory of the middle cerebral artery); also discrete perilesional edema impinging on the lateral ventricles	6, 21, 22, 37, 39, 41, 42, 43, 47; subcortical	5 months
5 Man	71	8	Ischemic	Basal ganglia, internal and external capsule, claustrum (all left)	11, 20, 25, 34, 47; mainly subcortical	1 year
6 Man	70	8	Ischemic	Left basal ganglia, anterior part of the left temporal lobe	21, 22, 38	5 months
7 Woman	68	11	Hemorrhagic	Hyperdensity in left temporal areas	20, 21, 22, 34, 38; subcortical	2 years
8 Man	64	26	Hemorrhagic	Left thalamus	Results not available	2 months
9 Man	63	13	Ischemic	Left frontal areas	4, 6, 44, 45	3 years
10 Woman	85	11	Ischemic	Left frontal hypodensity affecting the superior and middle frontal gyrus, corresponding to the territory of the left anterior cerebral artery	6, 8, 24, 32	5 months
11 Man	77	13	Ischemic	Left temporal parietal area	1, 2, 3, 6, 19, 20, 21, 22, 37, 38, 39, 40, 41, 42, 43, 44, 45, 46, 47; subcortical	10 months

TABLE 2. Neuropsychological Assessment of 11 Patients with Chronic Brain Lesions from a Stroke

Patient	Aachen Aphasia Test (Errors on Token Test)	Trail Making Test (seconds)		Visual Object and Space Perception Battery (Object Decision Task)	Neuropsychological Diagnosis
		Part A	Part B		
1	7	**138**	**Severe impairment (no score obtained)**	17/20	Executive deficit; no aphasia
2	**30**	**117**	**Severe impairment (no score obtained)**	16/20	Broca aphasia
3	**21**	**125**	**Severe impairment (no score obtained)**	17/20	Amnestic aphasia, executive deficit
4	Test not given	**141**	**431**	17/20	Neglect; no aphasia
5	**25**	Test not given	Test not given	16/20	Broca aphasia (moderate), attentional deficit
6	**17**	45	**285**	**12/20**	Broca aphasia
7	9	76	**410**	16/20	Amnestic aphasia
8	10	Test not given	Test not given	20/20	Executive deficit; no aphasia
9	**18**	72	190	19/20	No aphasia
10	3	Test not given	Test not given	18/20	Broca aphasia (moderate)
11	**50**	Test not given	Test not given	Test not given	Wernicke aphasia (severe)

Pathological scores are shown in bold type.

stimulus triplets. We called our test the "Tomato and Tuna Test" after 2 of the triplets.

The test stimuli can be obtained freely at http://www.amorydanek.de.

We took color photographs of the sets of actions and arrayed each set similarly to the KDT. In the TTT, the centered top photograph shows the accomplished goal of an action. In the TTT, the goal photograph appears first by itself. Then it is paired with the other 2 photographs. In the example in Figure 2, the accomplished goal is a house built out of playing cards. Of the 2 photographs beneath, the target depicts the correct preceding action (building the card house) and the distractor depicts an inapplicable action (distributing cards for playing). As with the KDT, sometimes the target is on the left, and sometimes on the right.

Notably, in contrast to the KDT, the TTT goal photograph never shows the effector of the action (here, the hand) or the action itself, only the final result of the action; however, the 2 action pictures show 1 or 2 hands performing the action.

We had pilot tested the TTT on 8 healthy volunteers, who completed the task and then rated the stimuli good or bad for comprehensibility and commented on their clarity. We replaced 5 of the original triplets that the volunteers found ambiguous.

TABLE 3. Study Groups' Demographic Data

Group	N	Men	Women	Age (Years)	Education (Years)
Patients	11	7	4	71.82 (6.35)	10.55 (5.82)
Matched controls	11	3	8	65.45 (8.01)	13.73 (5.44)
Young controls	15	3	12	23.93 (2.76)	17.27 (1.16)

Age and education data are shown as mean (standard deviation).

Procedures

We gave the 2 action understanding tests in 1 session: first the TTT and then the KDT. After the KDT, we gave the "old" controls the Mini-Mental State Examination (Folstein et al, 1975) to measure their general cognitive function; if they scored below 24/30, we excluded them from the analysis.

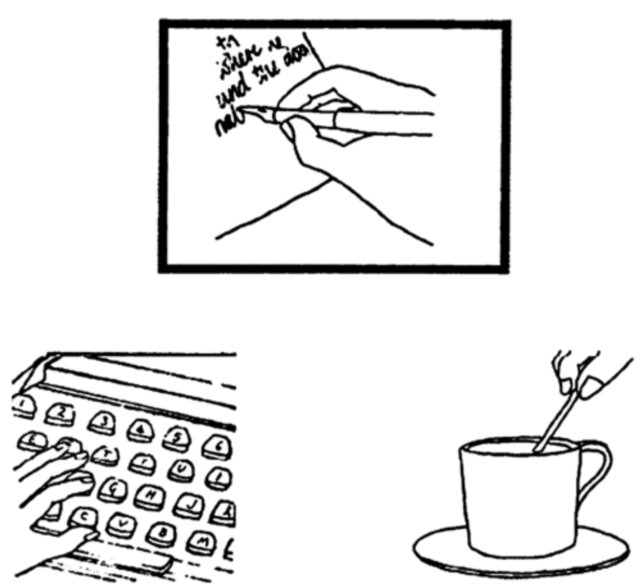

FIGURE 1. Sample stimulus display from the Kissing and Dancing Test. The presented action (framed) is Writing, the target is Typing, and the distractor is Stirring. (Reprinted from the *Journal of Neurolinguistics*, Vol 16. Bak TH, Hodges JR. Kissing and dancing—a test to distinguish the lexical and conceptual contributions to noun/verb and action/object dissociation; preliminary results in patients with frontotemporal dementia. Pages 169–181. © 2003, with permission from Elsevier.)

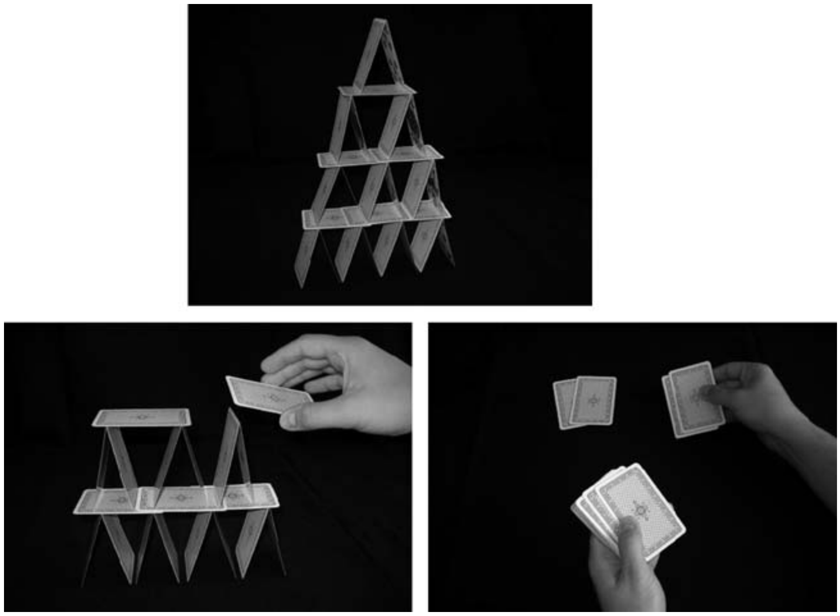

FIGURE 2. Sample stimulus display from the Tomato and Tuna Test. The action goal is a Card House, the target (preceding action) is Building a Card House, and the distractor is Distributing Cards for Playing. The actual test stimuli were shown in color.

For all the controls, the entire testing session lasted half an hour; for patients, about 1 hour.

TTT Procedure

The experimenter told each participant (the following text is translated from the Italian original):

The experiment will start with a picture that shows the final goal of an action. Please look at it carefully. Then two more pictures will appear. Please try to choose the picture that shows the correct preceding action, the one that comes before the goal. Press the left button if the correct picture is on the left side and the right button for the right side. Before we start, we will practice together. If you have any questions, please ask me now.

All participants were given 4 practice trials, the first 1 on paper and then 3 on the computer. Once they understood the procedure, the experimenter started the real test.

The 26 stimulus triplets were presented on the computer, in random order to prevent sequence effects. At the start of each trial, only the action goal picture appeared on the screen; 5 seconds later, the distractor and the target pictures were added. Participants had to choose between the distractor and target by pressing either the left or the right button on the keyboard. After they responded, the next action goal picture appeared.

We used Presentation Version 11.0 software (© 2013 Neurobehavioral Systems Inc, Albany, CA) to present the stimuli and to collect participants' responses and reaction times.

KDT Procedure

After the TTT, the experimenter told the participants the instructions for the KDT:

Here are three pictures. Please decide which one of the two at the bottom goes with the one at the top. Please point at the correct picture.

After 3 practice trials, the 33 picture triplets were presented in the small booklet. The experimenter wrote down the responses but did not record reaction times.

On both tests, participants responded manually, either by pressing a button or by pointing.

Statistical Design

Our dependent variables were reaction times and accuracy, measured in percentage of errors. Data were normally distributed (Kolmogorov-Smirnov test) and, hence, analyzed mainly with parametric tests using the statistical package SPSS 13.0 (International Business Machines, Armonk, NY). We set significance at $P < 0.05$ and all P-values were Greenhouse-Geisser corrected.

RESULTS

Group Analysis

In both the TTT and the KDT, the young controls performed faster and more accurately than the older, matched controls, who, in turn, performed faster and more accurately than the patients (Table 4).

Our 1-factor, univariate analysis of variance, conducted separately for each dependent variable, showed significant overall effects among the 3 test groups for all the dependent variables: for the variable TTT errors: $F_{2,34} = 33.78$, $P < 0.01$, $\eta^2_{partial} = 0.67$; for the variable

TABLE 4. Action Understanding Test Results in All Study Groups

Group	Tomato and Tuna Test		Kissing and Dancing Test
	Errors (% of All Trials)	Reaction Time (seconds)	Errors (% of All Trials)
Patients (n = 11)	25.23 (8.61)	7.77 (3.29)	14.88 (15.36)
Matched controls (n = 11)	7.75 (7.16)	5.3 (4.66)	4.96 (5.12)
Young controls (n = 15)	4.1 (4.47)	1.67 (0.38)	1.82 (2.51)

Data are shown as mean (standard deviation).

TTT reaction times: $F_{2,34} = 12.71$, $P < 0.01$, $\eta^2_{partial} = 0.43$; and for the variable KDT errors: $F_{2,34} = 7.07$, $P < 0.01$, $\eta^2_{partial} = 0.29$.

Because variances were heterogeneous and sample sizes unequal, we used the Games-Howell post hoc test for further analysis (Table 5). The KDT did not distinguish between our patients and the matched controls. On the TTT, the matched controls made significantly fewer errors than the patients ($P < 0.01$), but did not respond significantly faster. Not surprisingly, the young controls were significantly faster and more accurate than the patients on both tests (all P-values < 0.05). However, neither the KDT nor the TTT could distinguish between the matched and young controls.

Figure 3 compares all the groups' performance on both tests.

Table 6 lists the patients' individual results for the TTT and KDT. We defined as "impaired" any error score above a cutoff that we calculated by adding 2 SDs to the mean error score of the age-matched controls. We determined that an impaired TTT error score was $> 22.1\%$ and that 8 of our 11 patients exceeded it. An impaired KDT score was $> 15.2\%$ and 3 of our 11 patients exceeded it. We used the same calculation to determine an impaired TTT reaction time of > 14.6 seconds; no patient exceeded it.

Influence of Age and Education

We then analyzed only the data of the patients and their matched controls, to check for influences of age and education by correlating them with performance measures. On the TTT, age correlated significantly with reaction times (Pearson $r = 0.46$, $P < 0.05$), but not with accuracy. The older the participants were, the more time they needed for the task.

On both tests, education correlated negatively with the number of errors. For the TTT: $r = -0.52$, $P < 0.05$; for the KDT: $r = -0.46$, $P < 0.05$. Although a higher education was associated with fewer errors, education did not influence TTT reaction times. As expected, when we added the young control group to this analysis, we found that age and education correlated highly with both reaction times and error rates on the 2 tests.

Influence of Language Impairment

We compared the 7 patients who had aphasia with the 4 patients who did not have aphasia. On average, the patients with aphasia made 26.2% errors on the TTT versus 23.5% in the patients without aphasia. Notably, the patients with aphasia made 13.9% errors on the KDT versus 16.7% in those without aphasia. TTT mean reaction times were 7.8 seconds in those with aphasia versus 7.5 seconds in those without aphasia.

Comparing the patients with and without aphasia using t tests for independent samples yielded no significant differences for either errors or reaction times. This finding confirms our assumption that both the TTT and the KDT measure action understanding without relying on language abilities.

Comparison Between the TTT and KDT

As the TTT is a novel test, we compared it with the KDT, which has already been in use as a measure of action understanding. Comparing the error rates of the normal controls (we could not compare reaction times because we had collected them only for the TTT) using a t test for paired samples, we found that the TTT was significantly more difficult (mean error rate = 5.65%, SD = 5.92) than the KDT (mean error rate = 3.15%, SD = 4.06) with $t_{25} = 2.4$, $P < 0.05$. These results did not change when we added patient data. We interpret this difference as resulting from the higher demands of the TTT on action understanding, taking into account the sequential structure and goal orientation of actions—considerations that are not needed to solve items on the KDT.

Analysis of the TTT Stimuli

As the TTT is a new test, we analyzed the stimuli themselves. We sorted the 26 stimulus triplets by dis-

TABLE 5. Significant Differences Between Study Groups on the Games-Howell Post Hoc Test ($P < 0.05$)

Group	Tomato and Tuna Test		Kissing and Dancing Test
	Errors (% of All Trials)	Reaction Time (seconds)	Errors (% of All Trials)
Patients vs matched controls	*		
Patients vs young controls	*	*	*
Matched vs young controls			

*$P < 0.05$ statistically significant.

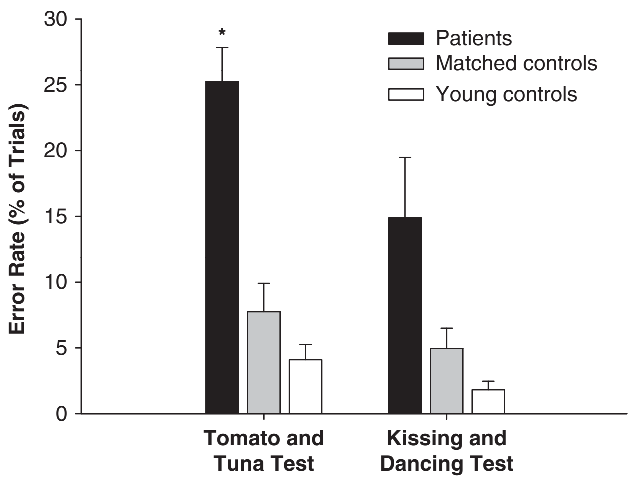

FIGURE 3. Performance by all participants on the Tomato and Tuna Test and the Kissing and Dancing Test. The error bars show standard errors of the mean. The asterisk denotes a significant difference between the patients and their matched controls on the Tomato and Tuna Test; the difference on the Kissing and Dancing Test was not significant. The patients performed significantly worse than the young controls on both tests; this difference is not marked on the graph.

tractor dimension and by whether or not the distractor photograph showed the use of a tool.

There were 2 categories of distractor dimensions. First, we had created "continuation distractors" from a continuation of the action sequence after the depicted goal had been achieved. For example, if the goal was a freshly baked cake, then cutting the cake with a knife would be a continuation distractor. Second, we had created "inapplicable distractors," actions unrelated to the goal. For example, if the goal was a glass filled with juice, then putting a flower into the glass would be an inapplicable distractor. Of our 26 stimulus triplets, 10 had continuation distractors and 16 had inapplicable distractors. Note that none of our distractors showed an unusual or inappropriate manipulation of an object, such as using a napkin as a hat.

Likewise, there were 2 categories for tool use: whether or not the distractor photograph showed the use of a tool. The term "tool" is to be understood in a broad sense, as any object used in some way to manipulate the target object. Of our 26 stimulus triplets, 16 distractor photographs showed tool use and 10 did not.

Appendix 3 lists all the TTT stimuli and their distractor and tool categories.

Paired *t* tests confirmed that our participants' error rates and reaction times did not differ significantly between the 2 distractor dimensions. This was true even when the 3 test groups—patients, matched controls, and young controls—were analyzed separately.

Interestingly, analyzing the tool use category yielded significant performance differences, but only in the patient group. The patients were significantly less accurate in responding to "tool use" stimuli (mean error rate = 30.8% of all tool use stimuli) than "no tool use" stimuli (mean error rate = 16.4%), with $t_{10} = 2.73$, $P < 0.05$. The patients did not show a difference between the 2 types of stimuli for reaction times. While the patients exhibited a bias toward making more errors for stimuli involving tools, the matched and young controls showed a balanced performance for stimuli with and without tools.

TABLE 6. Individual Patients' Performances on the Tomato and Tuna Test and the Kissing and Dancing Test

	Tomato and Tuna Test		Kissing and Dancing Test
Patient	Errors (% of All Trials)	Reaction Time (seconds)	Errors (% of All Trials)
1	16.0*	4.51	6.06
2	**30.77**	6.75	9.09
3	**36.0***	13.21	12.12
4	**28.0***	6.35	**51.52**
5	**30.77**	5.3	**27.27**
6	**36.0***	9.05	12.12
7	**23.08**	14.1	3.03
8	19.23	5.67	3.03
9	**26.92**	5.38	6.06
10	7.69	9.4	3.03
11	**23.08**	5.7	**30.3**

Scores above the cutoff (see text) signify impairment and are shown in bold type.

*The patient completed only 25 of the 26 trials.

DISCUSSION

We have designed a new test of action understanding, the TTT, targeted at assessing patients' ability to infer action goals from photographs. To test the TTT's reliability, we compared it to the KDT, another measure of action understanding.

Only the TTT distinguished between a sample of 11 brain-damaged patients and an age-matched control group. On the TTT, the patients had mean error rates of 25%, compared to 8% for the matched controls. The KDT was significantly easier, with mean error rates of 15% for the patients and 5% for the matched controls.

The TTT differs from the KDT in the need to represent an action sequence. In contrast to the KDT, the TTT requires participants to infer the preceding action from a picture of the accomplished goal of an action. We believe that the main difficulty of our new task lies in its reversed order, presenting the goal first and asking for the preceding action. To answer correctly, participants must mentally activate the complete sequence of steps in which the action is usually performed. Furthermore, the goal picture does not show any hands or tools performing the last step in the sequence, but only the accomplished goal itself.

For future studies, we could create a "re-reversed" version of the TTT that shows the correct temporal sequence by presenting the target and distractor first, and then the action goal. We expect that such a new version of the TTT would be less difficult because it would require less working memory and no sequencing.

Our present study replicates work by Fazio et al (2009), who found that patients with frontal aphasia had deficits in their ability to sequence pictures depicting human actions (Zanini et al, 2002). The TTT detected action understanding deficits in patients most of whose lesions were in brain areas that belong to the hypothetical mirror neuron system, but a systematic lesion analysis, including working memory areas (Wager and Smith, 2003), would be needed to allow further conclusions.

Furthermore, we had aimed to develop a test that would allow assessing action understanding completely nonverbally. Because both the TTT and the KDT turned out to be feasible for patients with impaired language comprehension, we further corroborated findings by Negri et al (2007), indicating that action understanding does not require the use of verbal labels. After a few practice trials, our patients could understand and follow the test instructions. We found no performance differences between our aphasic and nonaphasic patients. We take this as evidence that language impairments do not corrupt test performance. We propose that both the TTT and the KDT are nonverbal measures of action understanding that are well suited for patients with language impairments.

A stimulus-based analysis of the TTT revealed that our patients were specifically impaired in solving the task if the stimulus triplet showed a tool acting on the object. Actions involving the use of tools seem to be more difficult to understand, perhaps because the picture includes a second object. Also, to understand the action, participants must analyze the interaction between the object and the tool, and must check whether the tool is being handled correctly.

Unlike error rates, TTT reaction times did not differ significantly between the patients and their matched controls. We cannot exclude slight motor impairments in the matched controls as a possible explanation. In particular, having some controls with motor impairments could explain the high variance in the matched control group ($M = 5.3$ seconds, $SD = 4.66$ seconds). However, the finding that the young controls were not significantly faster than the matched controls argues against that interpretation.

In summary, we introduced the TTT as a novel measure of action understanding, emphasizing goals and the sequential nature of actions. This study shows the power of this test to unearth subtle action understanding deficits in a sample of brain-damaged patients when the deficits were not revealed by another, concurrently administered test. However, our sample does not allow a general recommendation of the TTT over the KDT, given that the tests' underlying concepts and aims differ. We were able to show that our task does not require intact language understanding; therefore, patients with aphasia can be tested without any language confounds. The TTT's high sensitivity and nonverbal design could make it a very useful test for future research.

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APPENDICES

APPENDIX 1. Kissing and Dancing Test: The 33 Stimulus Triplets Given to Our Study Participants

Presented Action	Target	Distractor
Writing	Typing	Stirring
Kissing	Dancing	Running
Swimming	Sailing	Flying
Shaving	Combing	Licking
Reading	Writing	Sewing
Eating	Drinking	Blowing
Posting	Writing	Drawing
Yawning	Sleeping	Jumping
Blessing	Praying	Crying
Singing	Dancing	Climbing
Ringing	Knocking	Peeping
Singing	Listening	Drawing
Sawing	Cutting	Knitting
Raking	Digging	Breaking
Riding	Driving	Standing
Greeting	Waving	Blowing
Climbing	Sliding	Crying
Baking	Icing	Writing
Ripping	Sewing	Erasing
Hitting	Kicking	Pulling
Dusting	Hoovering	Weaving
Buying	Robbing	Listening
Falling	Slipping	Swimming
Looking	Watching	Peeling
Arguing	Fighting	Touching
Mowing	Watering	Swinging
Planting	Sowing	Sweeping
Skiing	Skating	Swimming
Roaring	Barking	Biting
Watering	Pouring	Peeling
Playing	Clapping	Licking
Watching	Reading	Hammering
Cutting	Breaking	Driving

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APPENDIX 2. Tomato and Tuna Test: Stimulus Triplets

	Action Goal	Target (Preceding Action)	Distractor (Inapplicable Action)
1	Peeled banana	Peeling	Cutting the peeled banana
2	Card house	Building a card house	Distributing cards for playing
3	Balloon	Blowing up a balloon	Pricking the balloon with a needle
4	Blouse on a hanger	Hanging up the blouse	Folding the blouse on a table
5	Cake	Putting the cake in the oven	Cutting the cake
6	Jam on bread	Spreading jam on the bread with a knife	Eating the bread
7	Envelope with stamp attached	Putting the letter in the envelope	Posting the letter in a letterbox
8	Table set with clean plates	Distributing clean plates on the table	Taking away used plates after a meal
9	Wet clothes on clothes line	Fixing the clothes with pegs [clothespins]	Folding the dried clothes
10	Filled glass	Pouring juice in the glass	Putting a flower in the same glass when it is filled with water
11	Burning lightbulb	Screwing in a bulb	Shaking a lightbulb near one's ear
12	Packed suitcase	Packing the suitcase with clean clothes	Unpacking dirty clothes
13	Tomato salad	Slicing tomatoes	Mashing tomatoes with a fork
14	Blown-out candle	Blowing out the candle	Cutting the candle wick with scissors
15	Burning cigarette	Lighting the cigarette	Stubbing out the cigarette
16	Polished nails	Applying the polish	Removing the polish
17	Fried eggs	Breaking eggs into a pan	Scrambling the eggs
18	Nail in a wall	Hammering in the nail	Removing the nail
19	Pasta rolled on a fork	Rolling the pasta	Cutting pasta into pieces
20	Nicely folded napkin	Folding the napkin	Crumpling up the napkin
21	Grated cheese	Grating cheese with a grater	Cutting cheese into little pieces
22	Dishes on a drying board	Cleaning the dishes	Drying the dishes with a towel
23	Toothpaste on a toothbrush	Applying toothpaste with the tube lid open	Trying to apply toothpaste from a tube with a closed lid
24	Wrapped present	Wrapping the present	Tearing off the wrapping paper
25	Opened can of tuna	Opening the can with a can opener	Trying to open the can with a fork
26	Television (on)	Switching on the television	Cleaning the television screen

APPENDIX 3. Tomato and Tuna Test Action Goals: Distractor Dimension and Tool Use

		Distractor Dimension		Tool Use	
	Action Goal	Continuation	Inapplicable	Tool Use	No Tool Use
1	Peeled banana	♦		♦	
2	Card house		♦		♦
3	Balloon		♦	♦	
4	Blouse on a hanger		♦		♦
5	Cake	♦		♦	
6	Jam on bread	♦		♦	
7	Envelope with stamp attached	♦			♦
8	Table set with clean plates	♦			♦
9	Wet clothes on clothes line	♦		♦	
10	Filled glass		♦		♦
11	Burning lightbulb		♦		♦
12	Packed suitcase	♦			♦
13	Tomato salad		♦	♦	
14	Blown-out candle		♦	♦	
15	Burning cigarette	♦		♦	
16	Polished nails	♦		♦	
17	Fried eggs		♦	♦	
18	Nail in a wall		♦	♦	
19	Pasta rolled on a fork		♦	♦	
20	Nicely folded napkin		♦		♦
21	Grated cheese		♦	♦	
22	Dishes on a drying board		♦	♦	
23	Toothpaste on a toothbrush		♦		♦
24	Wrapped present	♦			♦
25	Opened can of tuna		♦	♦	
26	Television (on)		♦	♦	

REFERENCES

Ach N. 1910. *Über den Willensakt und das Temperament [About the Act of Volition and the Temperament]*. Leipzig: Quelle & Meyer.

Bak TH, Hodges JR. 2003. Kissing and dancing—a test to distinguish the lexical and conceptual contributions to noun/verb and action/object dissociation; preliminary results in patients with frontotemporal dementia. *J Neurolinguistics*. 16:169–181.

Bak TH, Hodges JR. 2004. The effects of motor neurone disease on language: further evidence. *Brain Lang*. 89:354–361.

Decety J, Grèzes J. 1999. Neural mechanisms subserving the perception of human actions. *Trends Cogn Sci*. 3:172–178.

Fazio P, Cantagallo A, Craighero L, et al. 2009. Encoding of human action in Broca's area. *Brain*. 132:1980–1988.

Fiez JA, Tranel D. 1997. Standardized stimuli and procedures for investigating the retrieval of lexical and conceptual knowledge for actions. *Mem Cognit*. 25:543–569.

Folstein MF, Folstein SE, McHugh PR. 1975. "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *J Psychiatr Res*. 12:189–198.

Gazzola V, Keysers C. 2009. The observation and execution of actions share motor and somatosensory voxels in all tested subjects: single-subject analyses of unsmoothed fMRI data. *Cereb Cortex*. 19: 1239–1255.

Hickok G. 2009. Eight problems for the mirror neuron theory of action understanding in monkeys and humans. *J Cogn Neurosci*. 21: 1229–1243.

Hommel B, Nattkemper D. 2011. *Handlungspsychologie [Psychology of Action]*. Berlin: Springer.

Jeannerod M. 1994. The representing brain: neural correlates of motor intention and imagery. *Behav Brain Sci*. 17:187–245.

Kilner JM. 2011. More than one pathway to action understanding. *Trends Cogn Sci*. 15:352–357.

Luzzatti C, Willmes K, De Bleser R, et al. 1994. Nuovi dati normativi per la versione italiana dell'Aachener Aphasie Test (A.A.T.) [New normative data for the Italian version of the Aachen Aphasia Test (A.A.T.)]. *Arch Psicol Neurol Psichiatr*. 55:1086–1131.

Molnar-Szakacs I, Iacoboni M, Koski L, et al. 2005. Functional segregation within pars opercularis of the inferior frontal gyrus: evidence from fMRI studies of imitation and action observation. *Cereb Cortex*. 15:986–994.

Negri GAL, Rumiati RI, Zadini A, et al. 2007. What is the role of motor simulation in action and object recognition? Evidence from apraxia. *Cogn Neuropsychol*. 24:795–816.

Prinz W. 1997. Perception and action planning. *Eur J Cogn Psychol*. 9:129–154.

Rizzolatti G, Craighero L. 2004. The mirror-neuron system. *Annu Rev Neurosci*. 27:169–192.

Rizzolatti G, Fogassi L, Gallese V. 2001. Neurophysiological mechanisms underlying the understanding and imitation of action. *Nat Rev Neurosci*. 2:661–669.

Rizzolatti G, Sinigaglia C. 2010. The functional role of the parieto-frontal mirror circuit: interpretations and misinterpretations. *Nat Rev Neurosci*. 11:264–274.

Rorden C, Brett M. 2000. Stereotaxic display of brain lesions. *Behav Neurol*. 12:191–200.

Rumiati RI, Papeo L, Corradi-Dell'Acqua C. 2010. Higher-level motor processes. *Ann N Y Acad Sci*. 1191:219–241.

Saygin AP, Wilson SM, Dronkers NF, et al. 2004. Action comprehension in aphasia: linguistic and non-linguistic deficits and their lesion correlates. *Neuropsychologia*. 42:1788–1804.

Tombaugh TN. 2004. Trail Making Test A and B: normative data stratified by age and education. *Arch Clin Neuropsychol*. 19:203–214.

Tranel D, Kemmerer D, Adolphs R, et al. 2003. Neural correlates of conceptual knowledge for actions. *Cogn Neuropsychol*. 20:409–432.

Van Overwalle F, Baetens K. 2009. Understanding others' actions and goals by mirror and mentalizing systems: a meta-analysis. *Neuroimage*. 48:564–584.

Wager TD, Smith EE. 2003. Neuroimaging studies of working memory. *Cogn Affect Behav Neurosci*. 3:255–274.

Warrington EK, James M. 1991. *The Visual Object and Space Perception Battery*. Bury St Edmunds, UK: Thames Valley Test Company.

Zanini S, Rumiati RI, Shallice T. 2002. Action sequencing deficit following frontal lobe lesion. *Neurocase*. 8:88–99.

