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Mimicking aphasic semantic errors in normal speech production: Evidence from a novel experimental paradigm

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Abstract

Semantic errors are commonly found in semantic dementia (SD) and some forms of stroke aphasia and provide insights into semantic processing and speech production. Low error rates are found in standard picture naming tasks in normal controls. In order to increase error rates and thus provide an experimental model of aphasic performance, this study utilised a novel method- tempo picture naming. Experiment 1 showed that, compared to standard deadline naming tasks, participants made more errors on the tempo picture naming tasks. Further, RTs were longer and more errors were produced to living items than non-living items a pattern seen in both semantic dementia and semantically-impaired stroke aphasic patients. Experiment 2 showed that providing the initial phoneme as a cue enhanced performance whereas providing an incorrect phonemic cue further reduced performance. These results support the contention that the tempo picture naming paradigm reduces the time allowed for controlled semantic processing causing increased error rates. This experimental procedure would, therefore, appear to mimic the performance of aphasic patients with multi-modal semantic impairment that results from poor semantic control rather than the degradation of semantic representations observed in semantic dementia [Jefferies, E. A., & Lambon Ralph, M. A. (2006). Semantic impairment in stoke aphasia vs. semantic dementia: A case-series comparison. *Brain*, 129, 2132–2147]. Further implications for theories of semantic cognition and models of speech processing are discussed.

Keywords: Semantic processing; Semantic dementia; Aphasia

1. Introduction

Semantic memory is our store of meanings and factual knowledge. It allows the comprehension of our environment and underpins our ability to communicate effectively both verbally and nonverbally (Rogers et al., 2004). Impairments to semantic cognition can be devastating and can result from neurodegenerative disease such as semantic dementia or aphasia due to cerebral vascular accident (CVA or stroke: Jefferies & Lambon Ralph, 2006).

Semantic dementia (SD) is a neurodegenerative condition where all types of concepts slowly degrade whilst other cognitive and language functions remain relatively intact (Hodges, Patterson, Oxbury, & Funnell, 1992; Snowden, Goulding, & Neary, 1989). Semantic dementia is caused by progressive bilateral atrophy of the anterior and inferior temporal cortex (Lambon Ralph, McClelland, Patterson, Galton, & Hodges, 2001; Mummery et al., 2000). Whilst there is a progressive degradation of semantic representations, this decline is not random and follows the same general pattern. For example, patients demonstrate better knowledge for general properties of objects than specific features in both receptive and expressive tasks (Hodges, Graham, & Patterson, 1995; Warrington, 1975). This results in the production of category superordinates (e.g., “animal” for horse, elephant or whale). Furthermore patients frequently use more typical or familiar labels within a semantic category in place of less familiar/typical exemplars on

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naming tasks (e.g., "cat" for leopard, deer or goat; Hodges et al., 1995; Rogers et al., 2004). Alongside omissions, these two error types (semantic category superordinates and coordinates) dominate the naming performance of semantic dementia patients and can be explained in terms of the gradual deterioration of underlying semantic representations (Lambon Ralph, Graham, Ellis, & Hodges, 1998; Lambon Ralph et al., 2001; Rogers et al., 2004).

A further feature of SD naming performance is differential error patterns to living (e.g., animals, plants) vs. non-living (man-made artefacts) stimuli. In a study consisting of 15 patients, Rogers et al. (2004) compared the proportion of errors that were omissions, superordinate or semantic coordinates of the items to be named. For the living stimuli (birds, water creatures and land animals), there were more semantic coordinate and superordinate errors in relation to omissions. The non-living items (household objects, vehicles and musical instruments) showed the reverse pattern with increased omissions compared to the other error types. Using an implemented PDP model of conceptual knowledge, Rogers et al. were able to show that this difference in error type is due to the organisation of semantic memory: living things tend to be more tightly clustered in semantic space compared to non-living items. When these semantic representations degrade in SD, the tightly packed representations are more likely to be confused with each other, leading to the production of coordinate or superordinate semantic errors. In contrast, although the representations for non-living items also break down, their relative isolation within semantic space means that there is less opportunity for confusion with other concepts and so omission errors are the most likely outcome. This same difference in error patterns is seen in other patient groups, e.g., herpes simplex encephalitis (e.g., Barbarotto, Capitani, & Laiacona, 1996; Borgo & Shallice, 2001; Warrington & Shallice, 1984) indicating that this is a general property of the semantic system.

Impaired semantic cognition due to stroke results from lesions in the temporoparietal and/or prefrontal regions and is often associated with Wernicke's, transcortical sensory and global aphasic subtypes (Berthier, 2001; Chertkow, Bub, Deaudon, & Whitehead, 1997; Jefferies & Lambon Ralph, 2006). Whilst stroke aphasics with semantic impairment (herein termed semantic aphasics) produce category superordinates and coordinates they also produce additional errors including semantic associative errors (e.g., 'bone' for the target dog) which are absent in SD patients (Jefferies & Lambon Ralph, 2006).

Although semantic dementia and stroke aphasia can both affect semantic cognition, until recently little research has been carried out that directly compares the deficits associated with the two aetiologies. Jefferies and Lambon Ralph (2006) directly compared the two groups across a variety of semantic tasks including picture naming. In order to compare SD to the closest possible stroke aphasia model, their patients were selected on the basis of showing multi-modal semantic impairments in the context of aphasia. Half had a transcortical sensory aphasia classification (TSA – i.e., able to repeat but not understand). The others had a classification indicating primarily semantic impairments. This selection criterion meant that, in practice, none conformed to classical Wernicke's aphasia (we refer to their aphasia group as semantic aphasia for short throughout this paper). Both groups, SD and stroke aphasia, produced the same proportion of correct responses (.41) and omissions (.37 and .32, SD patients and stroke aphasics, respectively). The SD patients produced more semantic errors overall (.45 compared to .33) with a higher proportion of these as category coordinates and superordinates (.99 compared to .73 of the total semantic errors) and very few associate errors (.01) compared to the stroke aphasic group (.27).

In addition to the error analyses, the two groups were compared on several further measures. Although the stroke aphasic and SD patients failed the same semantic tests and obtained relatively equivalent scores, there were clear qualitative differences between them (see Table 2, Jefferies & Lambon Ralph, 2006). The SD patients showed high correlations between scores on different semantic tasks and strong item consistency across different tests. This group were also highly sensitive to item familiarity/frequency. The stroke aphasic patients showed a different pattern. They were insensitive to the effects of familiarity/frequency. They only showed significant item consistency/correlations across tasks requiring the same type of semantic judgement (e.g., word vs. picture semantic association tests). Unlike SD patients, the semantic aphasia patients' scores across different types of semantic task (e.g., semantic association vs. picture naming) did not correlate.

A deregulation of semantic cognition (i.e., less precise executive control of semantic processing) rather than a degradation of core amodal semantic knowledge (as observed in SD) would seem to explain the behavioural profile of the semantic aphasic patients. Their deficit is multimodal (i.e., affects all verbal and nonverbal modalities of input and output) because all tasks, irrespective of which sensory/verbal modalities are involved, require at least some degree of semantic control. They demonstrate similar levels of semantic performance across different versions of the same semantic task (picture version of the camel and cactus test vs. all word version of the task) because the semantic control requirements are held constant. However, this consistency drops away when comparing across different semantic tasks because the semantic control requirements change; although the aphasic patients may be able to regulate the activation of information appropriate for one task (e.g., naming), they may be unable to reshape the information required for another test/situation (e.g., word-picture matching) even though the same concept is being tapped (Jefferies & Lambon Ralph, 2006)[1].

The implications of "dimmed" or degraded (SD) vs. "deregulated" (semantic aphasia) semantic cognition were explored further using phonemic cueing and miscuing in picture naming (Jefferies et al., submitted for publication). As expected, SD patients exhibited minimal effects of cueing and miscuing. In contrast, the aphasic patients (the patients tested in this study were the same as those reported in Jefferies & Lambon Ralph (2006)) demonstrated considerable effects of both cueing and miscuing. Phonemic miscues (e.g., table + /ch/) increased the activation of specific, semantically-related distractor words, making these competitors more likely to be selected instead of the target word. When provided with such phonemic miscues, the stroke aphasics generated more semantic errors that were consistent with the miscue (e.g., table + /ch/ → "chair"). Such results suggest that the presence or absence of cueing-miscuing effects can be used to distinguish between these different kinds of deficits of semantic cognition (see below).

While considerable knowledge can be gained by studying patient populations, it is necessary to assess non-brain damaged participants as well. In addition to careful explorations of normal performance, it can be revealing to create experimental models of patient-like symptoms in normal participants by manipulating experimental tasks. Using both methods, one can better ascertain the relationship between normal and pathological performance. The first aim of this paper was to induce semantic naming errors in controls. If one looks at naming errors from a general aphasic population then various different types are observed (Lambon Ralph, Moriarty, & Sage, 2002; Schwartz, Dell, Martin, Gahl, & Sobel, 2006). We concentrated, however, on the semantic errors made by the subtype of patients studied by Jefferies and Lambon Ralph (2006) – that is semantic dementia patients and aphasic patients with multi-modal semantic impairment. We selected, therefore, experimental paradigms that were most suited to eliciting semantic errors predominantly and excluded other methods that tend to produce phonological and other speech errors. Specifically, we explored the novel application of a picture version of the tempo naming technique developed by Kello and Plaut (2000). Kello and Plaut introduced a new technique, known as *tempo word naming*[2] to investigate subjective control and speed of responses. During tempo word naming, participants are presented with a series of evenly spaced beeps (forming a steady rhythm) along with a decreasing visual cue. The letter string to-be-read is presented on the final beep and the task is to pronounce the letter string in time with the beginning of the next beep (which does not actually occur). Using this method, participants' naming times can be experimentally manipulated by slowing or quickening the tempo.

In a series of experiments, Kello and Plaut (2000; Kello, 2004) compared the tempo word naming paradigm to a standard word naming paradigm under different conditions. Across all three experiments, word, nonword and articulatory errors increased as tempo increased (with a relative increase in lexicalisation errors). Kello and Plaut (2000) suggested that tempo word naming is a form of the more standard deadline naming method, which is widely used both in word naming and object naming studies. The obvious difference between the two paradigms is that in tempo naming there is an explicit and precise cue for when to initiate each response, rather than a single beep (or some other signal), often used in naming-to-deadline paradigms, which participants are asked to "beat".

Kello and Plaut (2003) used a PDP model to simulate the effects of the tempo word naming task. As well as an increased error rate, Kello and Plaut found that response duration also reduced as the tempo increased. They simulated all three effects (reduced response time and duration with an increased error rate) by forcing an increased processing speed in the network (increasing the unit input gain function (Kello & Plaut, 2003)). Importantly for the present study, these simulations indicated that a forced increase of processing speed comes at the expense of less controlled processing resulting in increased error rates. This follows from the increase in the gain function to all units: a response reaches threshold more rapidly (reducing response times) because the inputs to the relevant units are amplified but, in doing so, the model is less precise in activating the correct pattern, leading to errors.

The current study addressed four main questions:

1. Does the tempo procedure induce semantic errors, like those seen in stroke aphasic and semantic dementia (Jefferies & Lambon Ralph, 2006), when applied to picture naming in normal controls?
2. Is the tempo naming technique better than other methods of inducing errors in normal controls such as the standard naming-to-deadline paradigm (Vitkovitch & Humphreys, 1991; Vitkovitch, Humphreys, & Lloyd Jones, 1993)?
3. Is the pattern of errors across domains (living/non-living) the same as that found in the patient groups?

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[1] A helpful reviewer noted that 'reshaping' information could be interpreted as conscious processing, we were not making claims as whether the ability to reshape the information is conscious or not. It is possible that it may be done without conscious awareness, but also a patient could consciously try to reject distractors during a word-to-picture matching task. In essence, this does not alter our contention that semantic control or controlled semantic processing is impaired in the semantic aphasia patients.

[2] It should be noted that in their original paper Kello & Plaut used the term *tempo naming* not tempo word naming as we have adopted here. We adopted tempo word naming in relation to their work as to avoid confusion with the picture-based tasks used in this study.

4. If the tempo naming paradigm reduces semantic control then naming performance should become sensitive to the effects of cueing and miscuing as observed in semantic aphasia (Jefferies et al., submitted for publication).

Questions 1–3 are addressed in Experiment 1 and the final question is addressed in Experiment 2.

2. Experiment 1

2.1. Method

2.1.1. Participants

Thirty undergraduate psychology students (18–24 years old) from the University of Manchester took part. The majority received course credits, whilst the remainder volunteered. All were native speakers of English and had normal or corrected to normal vision.

2.1.2. Stimuli

The stimuli consisted of 144 pictured objects divided equally across living and non-living categories selected from the standardized set provided by Snodgrass and Vanderwart (1980). The 72 living items were each paired with a non-living item matched on frequency, familiarity, AoA and visual complexity (see Appendix A). All measures were obtained from Morrison, Chappell, and Ellis (1997). The matched pairs were divided into 6 subgroups and these were counterbalanced across the 6 experimental conditions using the latin square method. Half the subjects named objects using the tempo method first and half used the deadline method first. The 24 pictures in each condition were randomized in their order of presentation. Each item was seen one at a time in the centre of the computer screen, at a size of 142 × 142 pixels. All pictures were presented on a laptop computer using Superlab Pro (2000).

2.2. Procedure

2.2.1. Tempo naming

Participants sat approximately 18 inches in front of a computer screen wearing a headset with headphones and a microphone so they could hear the tempo beeps. Before the experimental items were presented, participants were exposed to a set of 20 practice items. They were informed that they would hear a series of beeps set to a given tempo and each beep would be accompanied by a fixation point on the screen with the exception of the fourth beep, when the picture-to-be-named would appear on the screen. They were asked to time their response to coincide with the fifth beep (see Fig. 1). Each trial was begun by the examiner pressing a key. Maintaining the tempo/rhythm rather than naming accuracy was emphasized. The practice trials were continued and repeated, if necessary, until the examiner judged the participants were naming the items in time with the tempo (fifth beep). The participants were then presented with the main experiment and again timing their responses with the tempo was emphasized over accuracy.

Based on pilot study results, using both the tempo picture naming paradigm and the naming to deadline paradigm, the tempos were set to 700 ms (baseline), 600 ms (medium) and 500 ms (fast). The order of the tempos was not counterbalanced in order to encourage participants to maintain the target tempo/rhythm. Each participant began at the baseline, followed by the medium and then the fast tempo. The trial events were the same as those in the practice session and are depicted in Fig. 1. A series of beeps was presented to coincide with the relevant tempo, with the picture presentations coinciding with the fourth beep and response coinciding with the fifth beep. Each trial was begun by the examiner pressing a key and each picture was presented for 300 ms in all tempo conditions. It was not expected that the subjects would be able to time their responses to coincide with the fifth beep on every trial; rather, the tempo was used as a method of putting the participants under pressure while responding (as per Kello &

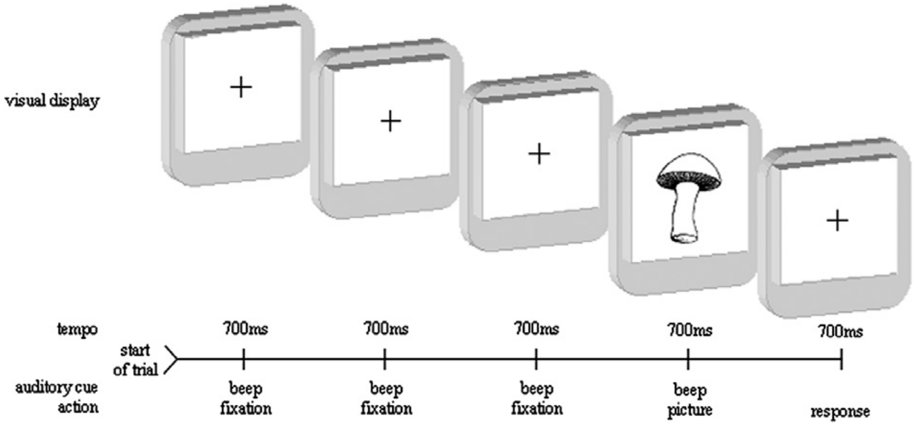

Fig. 1. Sample trial from the tempo picture naming task for Experiment 1.

Plaut, 2000). Reaction times were registered through the microphone and recorded by Superlab.

2.2.2. Naming to deadline

Participants sat approximately 18 inches in front of a computer screen wearing a headset with headphones and a microphone so they could hear the deadline beep. Before the experimental items were presented, participants were exposed to a set of 10 practice items. Participants were informed that pictures would be presented on the screen in front of them and shortly after the picture appeared, a beep would follow. They were instructed to try to 'beat the beep' and produce their response before the beep occurred. Speed of response was emphasized over accuracy of object naming. Once familiar with the procedure the participants took part in the main experiment.

The deadline lengths were matched to the tempos and the order of the deadlines matched the tempo procedure. Each trial was begun by the examiner pressing a key and each picture was presented for 300 ms in all the deadline conditions. Just as for the tempo procedure, it was not expected that they participants would be able to 'beat the beep' on all trials; rather the deadline was used as a method of putting the participants under an external time pressure while responding. Reaction times were registered through the microphone and recorded by Superlab.

2.3. Results and discussion

2.3.1. Reaction times

Equipment errors, false starts, and incorrect responses were all removed from the RT analysis. Data were analysed using a 2 (Task type: tempo naming, naming to deadline) × 3 (Speed: baseline, medium, fast) × 2 (Category: living, nonliving) repeated measures ANOVA with all items considered within subjects. All main effects were significant; Task type ($F(1,29) = 30.73$; $p < .001$) with the deadline task faster overall than the tempo task (634.77 and 683.67 ms, respectively); Speed ($F(2,58) = 121.23$; $p < .001$) with faster RTs in the quicker conditions (704.44, 657.74 and 615.48 ms baseline, medium and fast, respectively); Category ($F(1,29) = 16.97$; $p < .001$) with nonliving items named faster than living items (651.03 and 667.42 ms, respectively). There was also a significant Task type × Speed interaction ($F(2,58) = 96.77$; $p < .001$) as depicted in Fig. 2. This interaction indicates that there was more control over when to begin a response in the tempo naming task, whereas there was little difference overall in relation to presentation speed in the naming to deadline task; where participants seemed to respond as quickly as possible regardless of the actual deadline. There was also a Speed × Category interaction ($F(2,58) = 3.74$; $p = .03$) indicating that RTs for the living category decreased less overall with increased naming pressure than those for the nonliving items.

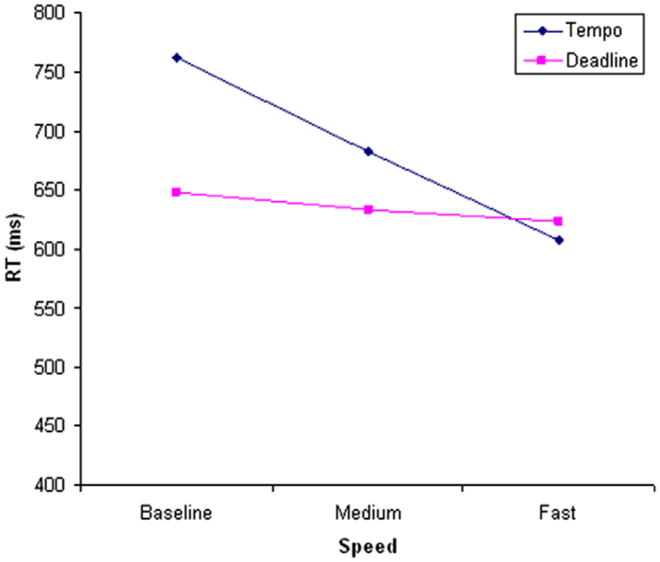

Fig. 2. Mean RTs in relation to task type and speed.

Subsequent analyses using repeated measures ANOVAs and separating the effects of the tempo and deadline conditions yielded significant effects in the deadline condition for Speed ($F(2,58) = 4.34$; $p = .018$) with modest declines of 13.95 ms from baseline to medium and of 10.29 ms from medium to fast (overall 24.24 ms baseline – fast) and Category ($F(1,29) = 10.09$; $p = .004$) with the nonliving items named faster than living items (625.99 vs. 643.55 ms). In the tempo condition there were again significant effects of Speed ($F(2,58) = 292.54$; $p < .001$) with large declines of 79.41 ms from baseline to medium and of 74.23 ms from medium to fast (overall 153.64 ms baseline – fast) and Category ($F(1,29) = 10.46$; $p = .003$) with nonliving items named more quickly than living items (676.06 ms vs. 691.29 ms).

2.3.2. Error analysis

Error data from 3 participants was not used due to technical difficulties; the remaining errors made were classified into 3 error types as follows: Semantic – a response that is either a superordinate (e.g., orange → 'fruit') or coordinate (a member of the same semantic category (e.g., fox → 'dog' or cherry → 'banana' or snail → 'snake')). Omission – no response given. Other error – naming part of the target (e.g. hand → 'finger'); a response bearing a visual relationship to the target (e.g., orange → 'ball'); a response having a relation to the target through functional or associative means (e.g., rabbit → 'carrot'); a real word or non-word response bearing a phonological and non-semantic relation to the target. Phonological relation means that target and response shared one or more phonemes in the same structural position (e.g., cone → 'phone') or two or more phonemes in any position (e.g., fish → 'shaft'; Dell, Schwartz, Martin, Saffran, & Gagnon, 1997); a description (e.g., scales → 'weighing thing').

The error rates were analysed using a 3 (Error type: semantic, omission, other) × 2 (Task type; tempo, deadline) × 3 (Speed: baseline, medium, fast) × 2 (Category: living, nonliving) repeated measures ANOVA with all variables treated as within subjects. All main effects were significant: Error type ($F(2,52) = 65.05$; $p < .001$) with proportionally more semantic errors overall (.11) followed by omissions (.07) then by other errors (.01); Task type ($F(1,26) = 6.10$; $p = .02$) with more errors in the tempo task (.07) compared to the deadline task (.06); Speed ($F(2,52) = 22.28$; $p < .001$) with increased error rates at the faster naming speeds (.05, .06 and .08 baseline, medium and fast, respectively); Category ($F(1,26) = 58.64$; $p < .001$) with more errors made to living (.09) than to nonliving items (.04). There were also four significant 2-way interactions (means for all interactions are provided in Table 1): Error type × Task type ($F(2,52) = 4.10$; $p = .02$); Error type × Speed ($F(4,104) = 8.15$; $p < .001$); Error type × Category ($F(2,52) = 55.15$; $p < .001$); Speed × Category ($F(2,52) = 4.91$; $p = .011$). Finally there was a significant 3-way interaction between Error type × Task type × Category ($F(2, 52) = 4.79$; $p = .012$) as depicted in Fig. 3.

Overall the participants made more errors to the living objects than the nonliving items following patterns seen in semantic aphasic patients and in SD. Others have also reported similar differential naming performances in older control subjects (Coppens & Frisinger, 2005). Vitkovitch et al. (1993) reported with their deadline naming paradigm, the most common error type for both living and nonliving items (structurally similar and dissimilar, respectively) was semantic errors but with a higher overall rate of semantic errors to living items. They did not report omission errors.

Table 1
Mean proportion errors for significant 2-way interactions

	Error type			Total
	Semantic	Omission	Other	
Task				
Tempo	.12	.07	.01	.20
Deadline	.10	.06	.02	.18
Total	.22	.13	.03	
Speed				
Baseline	.09	.05	.01	.15
Medium	.10	.07	.02	.19
Fast	.14	.08	.01	.23
Total	.33	.19	.04	
Category				
Living	.18	.08	.01	.27
Nonliving	.04	.06	.02	.12
Total	.22	.14	.03	

	Speed			Total
	Baseline	Medium	Fast	
Category				
Living	.06	.09	.11	.26
Nonliving	.04	.04	.05	.13
Total	.10	.13	.16	

Table 2
Mean proportion of errors for significant 2-way interactions

	Error type			Total
	Semantic	Omission	Other	
Cue				
Correct	.04	.02	.02	.08
Incorrect	.32	.07	.14	.53
Neutral	.10	.07	.05	.22
Total	.44	.16	.21	
Speed				
Slow	.12	.05	.04	.21
Fast	.18	.06	.11	.35
Total	.30	.11	.15	

	Speed		Total
	Slow	Fast	
Cue			
Correct	.02	.03	.05
Incorrect	.12	.23	.35
Neutral	.06	.08	.14
Total	.20	.34	

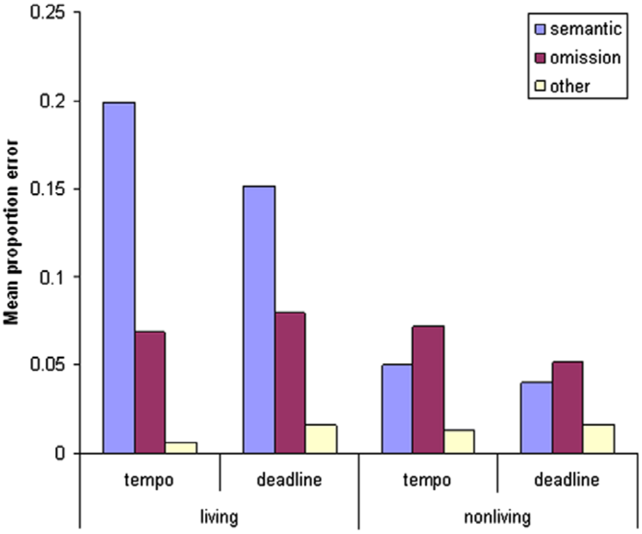

Fig. 3. Mean proportion error types in relation to task type and category.

The error data reported here differentiate further between living and nonliving items such that semantic errors were the most prominent for living items, but the majority of the errors for nonliving items were omissions. This matches the error patterns produced by SD patients where errors to living objects tend to be semantically related (coordinates, superordinates) and nonliving items produce higher omission error rates (Rogers et al., 2004). Interestingly, although few in number, the normal controls produced associative errors with more in the tempo paradigm ($n = 13$) than the standard deadline naming task ($n = 10$). As mentioned previously associative errors are absent in SD patients but they are produced by semantic aphasic patients (Jefferies & Lambon Ralph, 2006). Therefore, the tempo naming paradigm produced significantly more errors and matched the pattern of errors seen in semantically impaired patients, particularly semantic aphasic patients (Jefferies & Lambon Ralph, 2006) better than the deadline naming paradigm. This probably results from the fact that the tempo procedure is much more effective in speeding up participants' naming responses than the deadline procedure (see Fig. 2).

Experiment 1 established that tempo naming is an effective paradigm for increasing naming errors in control participants by reducing the time to control and complete speech production and semantic processing. This bears similarity to the semantic control deficit seen in aphasic patients with multi-modal semantic impairments (Jefferies & Lambon Ralph, 2006). Poor semantic control also explains why there is a beneficial effect of cueing in these patients and a detrimental effect of miscuing (Jefferies et al., submitted for publication). Experiment 2, therefore, investigated the effects of providing a correct or incorrect phonemic cue to control participants during the tempo picture naming task. If the tempo paradigm reduces controlled processing then a correct initial cue should help direct or control selection of the target name, whereas providing an incorrect cue should further hinder performance in the normal participants.

3. Experiment 2

3.1. Participants

Twenty-seven psychology students from the University if Manchester took part, most received course credits and the remainder volunteered. All were native speakers of English and had normal or corrected to normal vision.

3.2. Stimuli

The stimuli consisted of 60 pictured objects from the standardized set provided by Snodgrass and Vanderwart (1980) and other unpublished sources. Each picture was seen in each cue condition (correct, incorrect and neutral). In the correct cue condition the initial phoneme was used, the incorrect cue consisted of the initial phoneme of a semantically related word (e.g., picture of a tiger presented with '*l*' for lion) and the neutral cue was a beep. The items and their cues (correct, incorrect and neutral) were divided pseudorandomly into 3 sets and each set had an equal number of each cue type. Any given item only appeared in each set once. Therefore, each set contained all the items with one third having the correct cue, one third with the incorrect cue and the final third with the neutral beep. The order of the sets was counterbalanced across the participants and within each set the presentation order was randomized for each participant. The items were seen at two tempos slow and fast; half were seen at the slow tempo first and half at the fast tempo first.

3.3. Procedure

Participants sat approximately 18 inches in front of a computer screen wearing a headset with headphones and a microphone so they could hear the tempo beeps and auditory cues. Before the experimental items were presented, participants were exposed to a set of practice 40 items and the three cue types. They were informed that for each target item, they would hear a series of beeps or speech sounds (phoneme) and that these would be set to a given tempo. Further, each beep/phoneme would be accompanied by a fixation point on the screen with the exception of the fourth beep/phoneme, when the picture-to-be-named would appear on the screen rather than the fixation point. They were asked to time their response to coincide with the fifth beep/phoneme (see Fig. 1)[3]. Each trial was begun by the examiner pressing a key. As in Experiment 1, maintaining the tempo/rhythm rather than naming accuracy was emphasized. The practice trials were continued and repeated if necessary until the examiner judged they were naming the items in time with the tempo (fifth beep/phoneme). Once the participants were able to time their responses with the tempo they were presented with the main experiment.

Based on naming times obtained in a pilot study under normal confrontation naming conditions, the slow tempo for this group of items was set to 800 ms and the fast tempo 600 ms. The trial events were the same as those in the practice session and are depicted in Fig. 1.

4. Results and discussion

4.1. Reaction times

RT data from 3 of the participants was removed to due equipment failure. Data were analysed using a 3 (Cue; correct, incorrect, neutral) × 2 (Speed; slow, fast) repeated measures ANOVA with all factors as within subjects. Both main effects were significant: Cue ($F(2,44) = 43.14$; $p < .001$) with the incorrect cue (867.64 ms) producing the longest RTs followed by the neutral beep (808.35 ms) and then the correct cue (791.24 ms); Speed ($F(1,22) = 160.89$; $p < .001$) with the slow tempo producing slower RTs compared to the fast tempo (905.48 vs. 739.34 ms, respectively). The interaction was not significant ($F(2,44) = 1.40$; $p = .256$).

4.2. Error analysis

Data were classified according to the taxonomy listed previously and were analysed using a 3 (Cue: correct, incorrect, neutral) × 2 (Speed: slow, fast) × 3 (Error type: semantic, omission, other) repeated measures ANOVA, with all

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[3] In Fig. 1 the 'beeps' are shown. In the correct or incorrect cue conditions the beep was replaced by the corresponding phoneme.

variables as within subjects. All main effects were significant: Cue ($F(2,52) = 56.83$; $p < .01$) with the highest error rate occurring in the incorrect cue condition followed by the neutral and then correct cue conditions (.18, .07 and .02 incorrect, neutral and correct proportions, respectively); Speed ($F(1,26) = 48.30$; $p < .001$) with more errors at the fast (.12) compared to slow (.07) tempo; Error type ($F(2,52) = 35.82$; $p < .001$) with more semantic errors compared to the other error types (.15, .05, .07 proportion semantic, omission and other, respectively). All two-way interactions were also significant and the means for each are provided in Table 2; Cue × Speed ($F(2,52) = 16.50$; $p < .001$), Cue × Error type ($F(6, 186) = 42.10$; $p < .001$) and Speed × Error type ($F(3,78) = 9.44$; $p < .001$). The Cue × Error type × Speed interaction ($F(6,156) = 8.27$; $p < .001$) was also significant and indicates that all error types decreased to some degree in the correct cue condition relative to the neutral condition. There was, however, a non-uniform increase in errors in the incorrect cuing condition (when compared to the neutral beep): semantic errors increased at both tempos, omission errors remained constant while "other" errors increased only in the fast tempo (see Fig. 4).

As predicted providing the correct cue improved naming performance both in terms of reduced RTs but more importantly in reduced error rates. This mirrors the patterns seen in stroke aphasic patients (Howard & Orchard-Lisle, 1984; Jefferies & Lambon Ralph, 2006; Jefferies et al., submitted for publication; Lambon Ralph, Sage, & Roberts, 2000; Li & Williams, 1991; Pease & Goodglass, 1978; Stimley & Noll, 1991; Wilshire & Saffran, 2005) and previous reports of phonemic cueing using control participants (Hodgson, 1999; Nicholas, Obler, Albert, & Goodglass, 1985). Also, as predicted, an incorrect cue was detrimental to performance both in terms of longer RTs and increased error rates following the pattern seen in Jefferies et al. (submitted for publication). The error rate when provided with a neutral beep matched that of Experiment 1 when no cue was given (.22 and .20, Experiment 2 and 1, respectively). This pattern of results supports the contention that the tempo naming task provides an experimental model of the naming errors and behaviour found in semantically-impaired stroke aphasic patients, especially at the mild end of the severity spectrum.

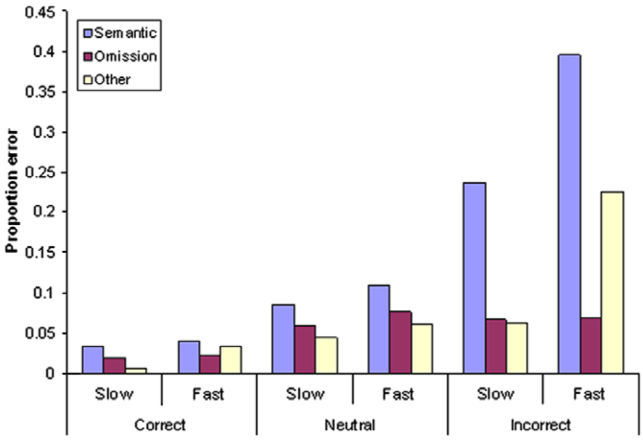

Fig. 4. Mean proportion error types in relation to cue and speed.

5. General discussion

Using a new picture naming paradigm – tempo picture naming, this study investigated semantic cognition in non-brain damaged control participants. The tempo naming paradigm not only increased the error rate in normal controls but matched the error patterns seen in semantically-impaired patients better than a standard deadline naming task. Four main findings mimicked the important aspects of the patients' behaviour, providing crucial support for tempo picture naming as an experimental model of patient behaviour. The critical findings here are: (1) the procedure induces semantic and omission errors but not phonologically related errors (as per our original motivation for these studies – see Section 1); (2) the distribution of errors across domains (living/nonliving) was similar in the controls to that reported in patients; (3) the tempo technique seems to reduce semantic control/controlled speech production; and (4) this loss of control is regained if a correct phonemic cue is provided yet augmented if an incorrect phonological cue is given. These features make the normal controls' performance closer to aphasic patients with multi-modal semantic impairments (semantic aphasia for short) than SD patients (Jefferies & Lambon Ralph, 2006; Jefferies et al., submitted for publication). These findings are discussed below.

Experiment 1 showed that, like SD patients and semantic aphasic patients, the normal participants had differential responses to living and nonliving stimuli. As predicted from computational models of semantic representation (Rogers et al., 2004), errors made to living things tend to be semantic superordinates or coordinates and errors made to non-living targets tend to be omissions. Rogers et al. were able to show that this difference in error type is due to the organisation of semantic memory: living things tend to be more tightly clustered in semantic space compared to non-living items. When these semantic representations degrade in SD, the tightly packed representations are more likely to be confused with each other, leading to the production of coordinate or superordinate semantic errors. In contrast, although the representations for non-living items also break down, their relative isolation within semantic space means that there is less opportunity for confusion with other concepts and so omission errors are the most likely outcome.

Consistent with semantic aphasia (and unlike SD patients) the normal controls produced some associative errors. These errors break the usual category boundaries but bear some relationship to the target, for example, producing 'carrot' for the target item *rabbit*. The exact mechanisms for this type of error remain unclear but their absence in SD patients and presence in semantic aphasia on naming tasks and in controls under speeded conditions suggest they too result from reduced semantic control.

How does the tempo paradigm reduce control and increase error rates? Two possibilities include a change in the speed–accuracy trade off and/or a reduction in general attention–executive resources due to the dual–paradigm nature of the tempo procedure. An explanation simply in terms of speed–accuracy trade-off seems less likely because one would expect the error rates and types to be the same as those produced on the deadline naming task in Experiment 1. An explanation in terms of divided attention–executive processing seems more likely; in this task not only are participants required to name pictures quickly but they are also encouraged to maintain a specific tempo. Attending to and maintaining the tempo will divert attention–executive resources away from the stages underpinning speech production – thereby making them more error prone. If correct, this notion would explain why normal participants under tempo naming conditions begin to mimic the semantic aphasia patients who have demonstrable attention–executive deficits as a part of their semantic profile (Jefferies & Lambon Ralph, 2006). This explanation fits with the wider idea explored by Jefferies and Lambon Ralph, namely, that semantic cognition requires a combination of semantic representations and semantic control in order to produce context and time-appropriate behaviours. Each of these interactive components can be impaired in different patients groups (e.g., semantic dementia vs. semantic aphasia). The key idea, then, is that normal semantic processing is demanding in terms of attention–executive processes and thus when these are called upon to deal with a second, concurrent process (maintaining a tempo) then there is a danger that insufficient executive resources will be devoted to semantic cognition.

The second experiment combined phonemic cues with the tempo picture naming paradigm. Errors increased with an incorrect cue and reduced when participants were provided with the correct initial cue. This follows patterns seen in semantic aphasia but not SD (Jefferies & Lambon Ralph, 2006; Jefferies et al., submitted for publication). Further, Jefferies et al. reported that their semantic aphasic patients produced more semantic errors in the incorrect cue condition, a pattern that was also repeated here. Jefferies & Lambon Ralph (2006) linked the difficulties in naming observed in their semantic aphasic patients to a deficit in *semantic control*; the patients' naming accuracy correlated with measures of executive function and was improved with the provision of a correct phonemic cue which reduces the need for intrinsic control in the speech production system.

Like Jefferies and Lambon Ralph (2006), we propose that semantic control is mediated by an executive system, external to the semantic system itself, which regulates or helps to bias the activation of posterior representations in order to produce context appropriate behaviour (for a computational instantiation of this general idea, see: Braver, Cohen, & Barch, 2002). As argued above, semantic control can become damaged in neurological patients or compromised in dual-paradigm situations such as those found in tempo naming. Specifically for naming, damaged or compromised semantic control should produce three key deficits: (a) participants will be less likely to activate the appropriate information for the task at hand – resulting in semantic errors and omission errors, when they cannot resolve one concept over another due to insufficient biasing; (b) participants will be slowed down even for correct naming because with poor efficiency it takes longer to settle on the target; and (c) in an interactive speech production system, cueing and miscuing act like external constraints on the poorly controlled system. Thus with the correct cue it is easier (speed) and more likely (accuracy) to settle on the correct target – while the miscue will actively pull participants away from the correct target.

The focus of this study has been on methods to elicit semantic naming errors in normal participants and comparing this experimental model to the relevant patient groups. The results also have implications for models of speech production. We finish, therefore, with a short note on this topic, particularly in relation to discrete (e.g., Levelt, 2001; Levelt, Roelofs, & Meyer, 1999) vs. interactive (e.g., Dell et al., 1997; Schwartz et al., 2006) accounts of speech production. The data point towards an interactive system. The phonemic cueing (both correct and incorrect) influenced selection at the lexical level: there was a reduction in errors and RTs in the correct cue condition, and an increase in errors (particularly semantic) and RTs in the miscue condition. In a discrete model, activation at the phonological level should not be able to influence selection at the lexical level: in the Levelt two-stage model semantic competition takes place and is resolved at the lemma level which is, by definition, non-phonological. As such, an incorrect phonological cue should not direct selection away from the target. In an interactive model, partial activation at the phonological level would reverberate back to the lexical level and assist in resolving any lexical competition. These results support those proposals which argue that semantics and phonology interact and are the primary basis of speech production (Lambon Ralph et al., 2000; Schwartz et al., 2006).

Appendix A

Items in the 6 lists used in Experiment 1, individual list means for the values are given as well as the overall means and (SD) for each category

	Non-living					Living			
	Freq	Fam	AoA	Comp		Freq	Fam	AoA	Comp
List 1									
Television	113	4.59	38.5	3.22	Eye	127	4.50	44.5	3.48
Umbrella	11	3.41	23.4	2.95	Spider	4	3.09	25.1	3.15
Tent	37	3.15	44.5	2.95	Sheep	20	2.86	44.5	3.30
Aeroplane	8	2.73	23.4	3.50	Duck	4	2.59	22.1	3.05
Pram	5	2.40	38.5	3.55	Owl	3	2.18	38.5	3.70
Trumpet	5	2.05	56.5	3.15	Donkey	9	1.95	50.5	3.10
Bellows	2	1.40	140.0	3.70	Armadillo	0	1.45	140.0	4.15
Caravan	7	2.85	56.5	3.20	Crab	4	2.55	50 5	3.75
Key	70	4.68	23.4	2.05	Cat	41	4.00	23.4	2.60
Necklace	2	2.86	50.5	1.78	Pear	2	3.23	44.5	1.20
Knife	35	4.82	23.4	1.95	Apple	18	4.48	22.1	1.75
Microscope	6	2.65	140.0	2.95	Cactus	2	2.70	115.0	2.15
Mean	25.08	3.13	54.88	2.91		19.50	2.96	51.72	2.95
List 2									
Vase	4	2.50	62.5	3.40	Fairy	11	2.30	62.5	3.00
Glass	125	4.45	44.5	1.95	Arm	104	4.73	38.5	1.80
Pond	14	3.60	44.5	4.05	Fly	17	3.23	56.5	3.55
Violin	4	2.14	62.5	3.75	Leopard	7	2.00	68.5	3.80
Guitar	6	3.00	62.5	3.10	Ant	4	2.75	62.5	3.70
Plug	6	3.59	68.5	2.50	Whale	6	3.15	56.5	2.85
Basket	18	2.27	38.5	3.85	Fox	10	2.50	38.5	4.02
Bath	44	4.65	23.4	3.10	Dog	69	4.05	22.1	2.70
Scissors	4	3.91	23.4	2.20	Leaf	15	3.41	25.1	2.75
Mitten	o	2.36	114.5	2.35	Nut	7	2.23	115.0	2.05
Sword	13	2.55	50.5	1.75	Lemon	13	2.95	44.5	1.30
Ruler	8	3.82	62.5	2.40	Tomato	7	3.64	68.5	1.98
Mean	20.50	3.24	54.82	2.87		22.50	3.08	54.89	2.79
List 3									
Pan	22	4.70	44.5	2.05	Thumb	22	4.64	38.5	2.40
Bottle	82	4.41	38.5	1.40	Foot	98	4.59	38.5	1.85
Helicopter	11	2.00	23.4	4.20	Elephant	12	2.20	23.4	4.12
Ship	44	3.35	56.5	3.35	King	89	3.00	56.5	3.70
Telescope	6	2.55	92.5	2.10	Nun	5	2.40	103.0	2.80
Peg	4	3.35	44.5	2.40	Ladybird	0	3.00	38.5	2.35
Flute	2	1.91	92.5	4.15	Peacock	3	1.91	92.5	4.25
Ladder	13	2.64	25.1	2.55	Squirrel	4	2.55	25.1	2.75
Shoe	14	4.68	22.1	3.20	Tree	72	4.50	22.1	3.45
Glasses	32	3.82	23.4	2.60	Flower	27	3.27	22.1	2.80
Glove	5	2.91	44.5	2.70	Strawberry	3	2.77	44.5	2.55
Cymbals	1	2.40	140.0	4.25	Celery	3	2.50	140.0	4.25
Mean	19.67	3.23	53.96	2.91		28.17	3.11	53.72	3.10
List 4									
Skirt	20	3.55	56.5	3.15	Hen	6	3.20	50.5	2.90
Ball	93	3.36	23.4	2.25	Fish	80	3.09	22.1	2.95

Appendix A (*continued*)

	Non-living					Living			
	Freq	Fam	AoA	Comp		Freq	Fam	AoA	Comp
Scarecrow	1	2.15	44.5	4.30	Mermaid	1	2.05	50.5	4.35
Arrow	8	3.27	62.5	1.60	Nail (finger)	0	3.15	56.5	1.85
Barrel	14	2.14	74.5	3.05	Camel	8	1.73	68.5	3.00
Diamond	8	1.65	86.5	3.10	Deer	6	1.73	86.5	3.35
Trousers	28	4.90	25.1	2.30	Finger	48	4.68	23.4	2.35
Train	68	3.64	25.1	3.45	Cow	22	3.18	23.4	3.85
Web	6	3.15	50.5	3.80	Grapes	8	3.00	56.5	3.35
Flask	4	3.05	102.5	2.55	Peach	3	3.01	103.0	2.55
Fork	12	4.55	23.4	2.20	Carrot	3	4.23	25.1	2.65
Lamp	21	3.73	74.5	1.90	Potato	11	3.91	74.5	2.20
Mean	23.58	3.26	54.08	2.80		16.33	3.08	53.38	2.95
List 5									
Torch	9	3.45	56.5	2.65	Bat	9	3.05	56.5	3.20
Cloud	30	4.05	56.5	1.15	Lips	61	4.67	50.5	1.55
Hammer	9	2.82	25.1	2.55	Rabbit	11	2.81	22.1	2.65
Whistle	8	2.45	50.5	2.30	Snail	3	2.45	44.5	2.70
Castle	24	3.45	38.5	3.45	Queen	50	3.05	44.5	3.90
Cannon	3	1.64	114.5	3.70	Ostrich	2	1.41	103.0	3.15
Slide	9	2.90	22.1	3.95	Butterfly	5	2.73	23.4	4.05
Bed	244	4.86	22.1	2.45	Hand	440	4.59	23.4	2.80
Sledge	1	1.82	86.5	3.05	Pumpkin	2	1.77	74.5	2.60
Fridge	4	4.48	56.5	2.40	Onion	9	3.95	68.5	2.85
Tights	4	3.70	74.5	3.50	Mushroom	5	3.20	62.5	3.12
Yo–yo	0	2.15	74.5	2.95	Pineapple	2	2.36	74.5	3.60
Mean	28.75	3.15	56.48	2.84		49.92	3.00	53.99	3.01
List 6									
Pen	19	4.64	44.5	2.45	Ear	42	4.59	44.5	2.85
Van	54	3.65	50.5	3.60	Nurse	31	3.70	50.5	4.30
Waistcoat	3	3.23	86.5	2.80	Beetle	5	2.95	86.5	3.05
Tractor	7	2.80	23.4	3.60	Mouse	8	2.59	23.4	3.00
Drum	7	2.41	50.5	2.65	Goat	12	2.00	56.5	2.80
Kite	3	2.14	38.5	2.70	Penguin	4	1.86	38.5	2.60
Windmill	7	1.59	50.5	4.60	Tiger	4	1.77	44.5	4.35
Pencil	15	4.0	38.5	2.05	Leg	63	4.73	38.5	2.15
Watch	37	4.27	38.5	2.95	Orange	27	3.37	38.5	2.12
Scales	9	3.20	86.5	3.10	Lettuce	6	2.82	74.5	3.15
Screwdriver	0	2.73	68.5	1.90	Cherry	6	2.43	74.5	1.60
Screw	7	2.77	80.5	2.90	Acorn	1	2.50	86.5	2.95
Mean	14.00	3.12	54.74	2.94		17.42	2.94	54.72	2.91
Overall mean	21.93	3.19	54.83	2.88		25.64	3.03	53.74	2.95
(SD)	(39.98)	(0.94)	(29.46)	(0.75)		(56.87)	(0.91)	(28.42)	(0.77)
$t(142)$	−0.46	1.02	0.22	−0.57					
p	.64	.31	.82	.57					

t-Test results showing the overall lists did not differ are also provided. *t*-Tests for the 6 sublists were also computed and the sublists did not differ on the four measures.

Freq, frequency; Fam, familiarity; AoA, age-of-acquisition; Comp, visual complexity.

All measures were obtained from (Morrison et al., 1997).

Appendix B

Items and the cues used in Experiment 2

Target	Correct cue	Incorrect cue
Apple	a	p
Arm	a	l
Bicycle	b	k
Brush	b	k
Bus	b	k
Butterfly	b	m
Car	k	b
Cat	k	d
Caterpillar	k	b
Chair	ch	t
Cloud	k	s
Coat	k	h
Comb	k	b
Cow	k	b
Cup	k	m
Desk	d	ch
Dog	d	k
Door	d	w
Dress	d	k
Ear	ee	n
Envelope	e	l
Eye	i	n
Finger	f	th
Flower	f	r
Foot	f	m
Goat	g	sh
Hand	h	f
Hat	h	k
Horse	h	d
Jumper	j	k
Knife	n	f
Leg	l	a
Lemon	l	o
Lion	l	t
Mitten	m	g
Moon	m	s
Mouse	m	k
Needle	n	p
Nose	n	ee
Orange	o	l
Pear	p	a
Rabbit	r	h
Screw	s	n
Screwdriver	s	h
Seal	s	w
Sheep	sh	l
Shirt	sh	t
Skirt	s	d
Snail	s	k
Sock	s	sh
Spider	s	f
Spoon	s	f
Sun	s	m
Swan	s	d
Table	t	ch
Television	t	r
Thumb	th	f
Tiger	t	l
Trumpet	t	h
Vase	v	j

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