Meaning Construction, Spatial Language, and Past History.

Ronan O'Ceallaigh (ronan.oceallaigh@northumbria.ac.uk)
Cognition and Communication research centre, Northumbria University
Newcastle Upon Tyne, NE1 8ST, UK

Kenny Coventry (kenny.coventry@northumbria.ac.uk)
Cognition and Communication research centre, Northumbria University
Newcastle Upon Tyne, NE1 8ST, UK

Abstract

The fact that word meaning varies according to context presents a real challenge for models of language comprehension. In this paper we explore the application of dynamic systems theory as a means of explaining how spatial prepositions vary in meaning as a function of both object knowledge and immediate past history of use. Using an object placement task (following Carlson-Radvansky, Covey & Lattanzi, 1999), Experiment 1 provides evidence of a dichotomous interpretation for *over/under/above/below* between functional and geometric meanings. Experiment 2 shows that choice of interpretation is directly affected by similarity between probe trial objects and prime trial objects, and moreover that the number of prime trials impacts placements on probe trials. These results are consistent with dynamic systems theory, and the implications of this for meaning construction are explored.

Keywords: Spatial prepositions; dynamic systems theory; object placement.

Introduction

Words vary in meaning according to the context in which they are used, and words also can come to have novel meanings in specific contexts. For example, the word *over* can be used in a multitude of different ways, and the likelihood with which a particular sense is used varies as a function of the objects involved and the context in which the objects occur. While *The tablecloth is over the table* usually involves direct contact between the table and tablecloth, *The light is over the table* does not. However, if the tablecloth has just been bought and is still in its wrapping, *The tablecloth is over the table* is unlikely to involve direct contact.

In dialogue, speakers must consider not only their previous use of a term/expression and knowledge of the world, but also the interlocutor's point of view in order to communicate the particular meaning that he/she seeks to convey. Saying "place the thingy to the left of the widget" is too ambiguous to comprehend unless more information has been provided, such as previously agreed meanings of "thingy" and "widget", gestural communication, or a known goal task.

In essence theories of meaning must be able to account for the flexibility of meaning that human beings are capable of, capturing a whole host of contextual parameters that unfold in real time.

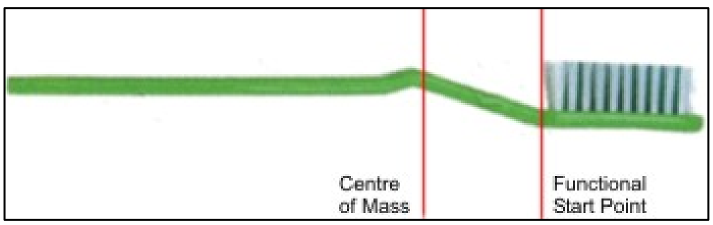
Spatial preposition comprehension

Imagine you are asked to *Place Object A above Object B*. Using such an object placement task, Carlson-Radvansky, Covey, and Lattanzi (1999) found object placements in response to such expressions were affected not only by the spatial relation/geometry denoted by the preposition, but also by knowledge of the objects involved and how they might typically interact. While participants exhibited a general tendency to place Object A (the Located object, hereafter "LO") between the functional part and centre-of-mass of the reference object (Object B, hereafter "RO") (see Figure 1), Carlson-Radvansky et al. also found that participants tended to place LOs more towards the functional part of the RO (e.g., the bristles of a toothbrush) if they were functionally related to the RO (e.g., a toothpaste tube) than when they were unrelated (e.g., a tube of paint).

These placement behaviors have been modelled successfully in the Attentional Vector Sum (AVS) by Carlson, Regier, Lopez, and Corrigan (2006), extending the original AVS model which did not consider functional relations between objects (Regier & Carlson, 2001). Here, language comprehension is considered to be informed by attention to the visual form of the reference object, and weighted by the functional part of the RO in the case of object pairs which typically interact, constructing a vector sum position for placement. Although this supports the view that language is dynamic based on situation, in this case the objects that prepositions were relating, Carlson et al. note that there may be other ways in which geometric and functional information can be combined, consistent with the "functional geometric framework" (Coventry & Garrod, 2004).

According to the functional geometric framework, spatial language comprehension involves constructing the most informative model that associates located and reference objects as a function of multiple constraints that unfold on-line over time. This can involve selecting between a number of interpretations, including geometric processes and functional simulations, with the particular interpretation based on the saliency of the various processes at any given point in time. So the most informative interpretation of *The toothpaste tube is above the toothbrush* may involve direct placement over the bristles of the toothbrush (given past knowledge of how the objects typically interact) while one might infer that *The paint tube is above the toothbrush* involves a geometric relation alone. Critically, an analysis of mean placements may either represent true between placements, or different ratios of complete functional and geometric placements mediated by knowledge of typical object interactions. In other words participant placements may reflect selecting between functional and geometric interpretations as a function of the context in which the expressions and placements occur. Experiment 1 tests which of these possibilities is the case. In turn, the selection between geometric and functional placements may be affected by similarity between the current objects to be placed, and past objects, and associated spatial expressions and placements. Dynamic systems theory affords a natural means of incorporating past history of use as a predictor of future interpretation. Experiment 2 tests predictions from dynamic systems theory, which we briefly outline next.

Figure 1 – Identification of centre-of-mass and functional



part of a reference object

Spatial Language and Dynamic systems theory

Dynamic systems have been successfully utilized to investigate a range of tasks, and have been applied to spatial language previously in relation to viewing spatial language and spatial memory as coupled systems (Lipinski, Spencer, & Samuelson, 2004), and as a means of understanding reference frame selection (Schultheis, 2007).

Perhaps the most exciting application of dynamic systems theory to behavior is the case of understanding the A-not-B error (Smith & Thelen, 2003). Incorrect searching behaviour on the part of infants to object locations was considered in a time dependent and multicausal system, allowing the behaviors of various age groups to be explained as an effect of memory. The model was then able to make multiple novel predictions that were subsequently shown to be supported in further experimental manipulations.

This leads to the development of a methodology in which searching for the exact meaning of a spatial preposition could be investigated and modeled. If "attractors" to spatial locations are built in the manner of the A-not-B error, then how do these attractors influence the comprehension of language after particular locations are previously used multiple times? Dynamic systems theory would suggest that previous similar actions would make similar placements more likely, where as previous dissimilar actions would interfere with placements. We test this prediction in Experiment 2.

Experiment 1

The first Experiment had two goals. First, the language comprehension task used by Carlson-Radvansky et al. needed be modified to remove any possible time dependent confounds within the task and to provide appropriate data for a dynamic systems interpretation. A baseline for spatial language comprehension without prior experience of the task involved should be produced in order to later investigate the influence of prior use, and a design similar to the A-not-B experiment would investigate whether prior actions could influence later language comprehension. Second, we aimed to establish the extent to which participants place objects between the functional part and centre-of-mass, consistent with the AVS model (and the Carlson-Radvansky et al. interpretation of their results), or whether participants select between functional and geometric placements, consistent with two attractors in a dynamic system of spatial preposition meaning. We also further asked whether verbal context may also mediate placement behavior.

Design

A between subjects design was adopted with a single trial run for each participant to eliminate any potential bias from previous experience within the experiment. Trials were varied in a 2(functionally related/functionally unrelated located objects to the reference object)x2(verbal context implying function given/not given)x2(high/low direction of use)x2(functional/geometric prepositions) design. Spatial prepositions were grouped as implying function, "over" in the high direction of use condition and "under" in the low condition, or implying geometry, "above" in the high and "below" in the low condition, following the distinction reported by Coventry, Prat-Sala and Richards (2004).

Method

Participants

One hundred and twenty eight members of the public participated for a small payment. They were informed of their right to withdraw from the study at any time, and gave informed consent.

Stimuli

Digital photographs were taken of eight asymmetrical objects with functional parts removed from the centre of mass, and with a vertical axis of interaction (for example, an *axe*, whose blade is the functional part, presented horizontally). Half of the objects had a direction of use from above (e.g., a fishing net), and half from below (e.g., a can opener), and objects were split equally to interact on the left or right side. These photographs were then normalized for size, at half the width of an A4 page, and printed in black and white in the centre of the page. Two further objects were then digitally photographed for each reference object. A functionally related object was chosen for its interaction with the other object (e.g., a *nail* with a hammer), and a non-functionally related object was chosen to match the similar size and shape of the functional object, and to have a possible but not standard interaction with the other object (e.g., a mascara applicator, which could be destroyed by a hammer). These images were then resized in relation to the reference object, and printed in black and white.

One set of stimuli was assigned to each participant, and the combinations of object relatedness, context condition, and preposition used were randomly assigned to each participant. Each asymmetrical object (hammer, axe, etc.) was presented with the functional object or the non-functional object.

Procedure

Participants were informed that they would be asked to place an image of an object in relation to another object, and that this may be proceeded by another instruction to imagine a scenario.

For each participant, the asymmetrical object was first placed on a clipboard. In the cases where context was to be given, the participant was then told to imagine a scenario, e.g., "Imagine you are making tea". The contexts given for both the functionally related and unrelated objects always involved or implied interaction with the functional part (e.g., for a teapot as a reference object, "Imagine you are going to make tea" is given as context for the functionally related teacup, and "Imagine you are going to clean sports equipment" is given for the functionally unrelated baseball). The image of the other object was then handed to the participant with blue tack attached to the back, and they were told to place that object in relation to the other object already placed. The resulting placements were then stored. Four prepositions were used (*over, under, above, below*) and these were rotated around objects (depending on the appropriate direction of interaction).

Results

The centre-of-mass for each reference object was calculated by superimposing a millimeter grid over the original image, recording which grid points fell above the object, and calculating the mean for those grid points. Placement coordinates were then recorded from the original placements by measuring the centre of the placed object on the millimetre grid of the reference object. These placements were then normalized across materials. The start point of the asymmetrical object was taken as 0, and the start of the functional part of the object as 1.

These normalized placements were passed through a 2 (functional versus non-functionally related objects) X 2 (context versus no context given) X 2 (functional versus non-functional prepositions) X 2 (high versus low direction of use) repeated measures analysis of variance (ANOVA). There were main effects of functional relatedness, $F_{(1,127)}= 28.683$, $p < .05$ and direction of use, $F_{(1,127)}= 4.382$, $p < .05$. Relatedness increased the mean deviation toward the functional part from 0.691 in the non-functionally related condition to 1.072 in the functionally related condition. A high direction of use, where participants were asked to place the object above or over the other object, was associated with a greater mean deviation to the functional part (0.940) than when participants were asked to place objects under or below (0.800). There was also a significant interaction between context and direction of use, $F_{(1,127)}= 4.987$, $p < .05$, however follow up tests did not show a significant interaction in either the high or low direction of use conditions.

Table 1 - Categorical placements by condition.

Relatedness	Non Functional		Functional	
Context	Not Given	Given	Not Given	Given
Centre	12	9	6	2
Between	10	11	10	6
Functional	10	12	16	24

Categorical results

The normalized placement data was then reclassified according to categories, where a placement with a value of more then or equal to 1 was classified as Functional, less then or equal to the centre of mass of the associated reference object as Centre, and less then 1 and more then the centre of mass as Between. The counts of classified placements broken down by functional/non-functional object relationships and context/no context given conditions are shown in Table 1. The overall count of placements was 29 Centre placements, 37 Between placements, and 62 Functional placements. This shows that the majority of placements are not between the centre of mass and functional part of the reference object, although some are. As can be seen from Table 1, when context and functionally related objects were presented to the participant, there was a large number of Functional placements compared to the number of Centre and Between placements. A chi-square test was run on this interaction and it was found to be significant ($chi^2 = 16.566$ $p < 0.05$).

Discussion

The findings of this experiment have partially replicated the findings of Carlson-Radvansky, Covey and Lattanzi (1999) in that mean placement analyses revealed between placements, with a greater deviation towards the functional part for the functional related objects.

However, the analyses of the categorical data show that the mean placement analyses do not reveal the whole picture. When the placements were categorised individually, between placements did not make up the majority of the overall placements for the functional or non-functionally related objects. This does not support the AVS model (although there were some between placements), but instead suggests a dichotomous relationship where listeners are choosing a particular interpretation of the spatial preposition, based on available knowledge, including object knowledge, situation, and knowledge about the world. Between placements can be regarded as a compromise between functional and geometric placements, rather than a normative form of placement.

Experiment 2

If deciding how to interpret a spatial expression in order to place objects involves selecting between functional and geometric placements, one can ask if the interpretation of previous spatial expressions and associated placements impacts on interpretation and placement on a given trial. The dynamic model of the A-not-B error has shown that prior information can have an effect on a searching task, and that the number of prior searches affects the likelihood with which a given location is chosen. The likelihood with which children exhibited the A-not-B error was affected by the number of times the object had been hidden repeatedly at location A. (Smith & Thelen, 2003)

Consistent with the dynamic model and associated data from the A-not-B error, we predicted that the number of previous placements for the same spatial terms and the level of similarity between prime and probe trials would affect placement behavior on probe trials. If a participant is repeatedly shown similar object pairs and then shown a final similar pair, the placement is expected to be clearly within that interpretation. However, if the participant is shown a set of similar pairs followed by a dissimilar pair, the placement should be affected by the amount of similar pairs previously shown. Specifically, if a participant is shown a functionally related pair of objects after seeing and interacting with a number of non-functionally related pairs of objects, then placement should be dependent on the number of pairs they have been shown. After sufficient non-functional placements, the placement of a functionally interactive object should migrate away from the functional part of the reference object.

In order to test this idea, a priming paradigm was introduced to the object placement task. Participants performed a series of object placement trials, and we varied both the number of prime trials presented prior to the key probe trial, and the similarity (in terms of object functional relations) between the prime trials and the probe (see Figure 2). Either two or four prime trials were presented prior to the probe trial to test the effect of the attractor towards functional or geometric interpretations of the spatial preposition, with four prime trials potentially sufficient to interfere with comprehension in the probe trial (consistent with the A-not-B error data).

Design

A between subjects design was again used. Each participant was given a single prime/probe set, with the level of interaction between objects within the prime trials either functionally related or functionally unrelated. The level of interaction in the probe trial then was either the same or different to the prime trials. The amount of priming was varied between two and four trials due to previous practice effects found in an exploratory experiment, allowing the time course of prior history to be modeled. Spatial prepositions were again grouped as implying function (*over/under*), or implying geometry (*above/below*), and were manipulated in the same manner as functional relatedness.

The direction of use of the asymmetrical object varied within subjects, with appropriate functional or geometric spatial prepositions assigned according to the preposition condition. The original position of the object to be placed, to the left or right of the object in the same horizontal plane, was counterbalanced between subjects, as was the orientation of the asymmetrical objects balanced between the functional part being on the left or right of the screen.

Method

Participants

141 members of the public and students at Northumbria University participated in the experiment at a number of locations, including a social club, a public library, and the library at Northumbria University. All gave informed consent and were unaware of the purpose of the study.

Stimuli

10 digital images of asymmetrical objects were taken, where the functional part of the object horizontally diverged from the centre of mass of the object. Paired with each reference object, images were taken of two located objects which were functionally associated or unassociated to the other object.

Procedure

Participants were approached and asked if they could spare two minutes to take part in a language experiment. Participants who agreed were then asked to sit in front of a touch screen monitor and allowed time to read the information screen provided. If they gave consent they were shown a training screen which explained how the experiment would progress and given the opportunity to practice using the touch screen with practice materials. (see Figure 1)

A screen then appeared asking if they wished to proceed to the experiment, with a ‘yes’ and a ‘no’ button displayed on screen, if they then pressed the ‘yes’ button, the experiment was run. Each participant completed 3 to 5 trials, moving an object across the screen with their finger, and the end position on screen was recorded in pixels.

In each trial, the participant was shown first shown an instruction sentence for five seconds before the two objects were displayed. The participant then had five seconds to touch the object to be placed, and an unlimited time to place it according to the instructions. Once the participant did not touch the object for a period of five seconds, the trial was finished and the next trial began.

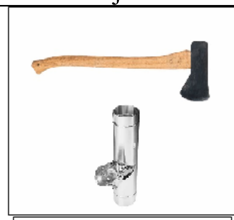
Instruction	Objects
"Place the pipe below the axe."	
"Place the oil paint tube above the toothbrush"	
"Place the can below the can opener"	

Figure 2 - A example material set for a participant, where 2 prime trials with functionally unrelated objects are followed by a probe trial with functionally related objects (a can and a can opener).

Results

Participants failing to complete trials were eliminated from the analyses, leaving 128 participants remaining. The horizontal position of the placed objects was then normalized across materials following Carlson-Radvansky et al. The mean horizontal position of the placed object was taken from averaging the left and right edges of the object image, which was then normalized according to the related asymettrical object. The functional start point, where the functionally interactive component is closest to the centre of the other object, is denoted as 1, and the opposite end of the object is denoted as 0.

When these normalized placements were put into a 2x2x2x2x2 ANOVA (Functional/non-functional relatedness x Prime/Probe trial x 2/4 number of prime trials x above/below direction of use x congruent/incongruent probe to prime relationship), main effects were found for relatedness ($F(1,424)=24.575$, $p<0.05$) and direction of use ($F(1,424)=98.070$, $p<0.05$), consistent with the results of Expt. 1. Overall, when objects were more functionally related the normalized placements tended towards the functional part of the other object (0.883) than when objects were unrelated (1.040). Objects placed above the asymetrical object also tended more towards the functional part of it (1.119) then those placed below (0.804).

Critically, there was also a significant interaction between relatedness, number of prime trials, and congruence of probe to prime ($F(1,424)=4.327$, $p<0.05$). As can be seen in Figures 3 and 4, the differing prime and probe combinations, NF-F and F-NF, do not behave in the same manner with 2 prime trials as they do with 4 prime trials. After two functionally related object trials, placements in the nonfunctional condition tended strongly towards the centre of mass, and after two non-functionally related object trials, placements in the functional condition tended strongly toward the functional part. Yet after four prime trials, both the functional and non-functional incongruent placements were between the functional part and the centre of mass.

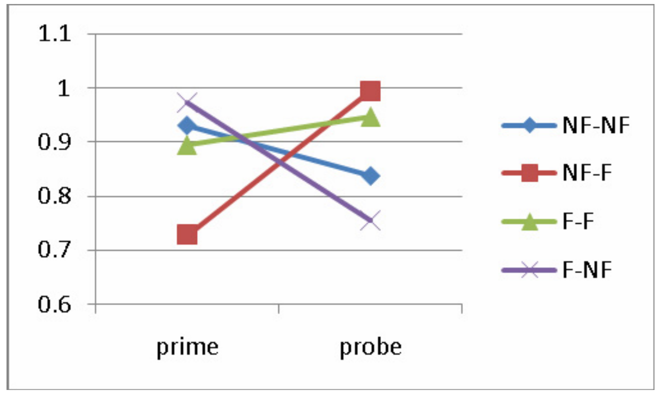


Figure 3 – Normalised placements in the 2-prime condition. NF stands for non-functionally related objects, and F for functionally related objects, so that NF-F is two non-functional trials followed by a functional trial.

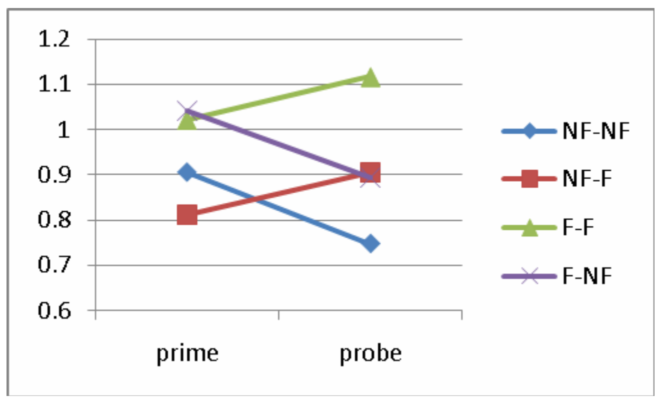


Figure 4 – Normalised placements in the 4-prime condition.

Categorical results

When placements were categorized as being either Functional, with a normalized placement greater than or equal to 1, Centre, with a normalized placement lesser than or equal to the centre of mass point of the asymmetrical object, or Between, with a normalized placements between 1 and the centre of mass point of the object, the placement frequencies were as follows: Functional (291), Centre (80) and Between (84).

Table 2 - Probe categorical placements

Relatedness	Non Functional		Functional	
Congruent	Different	Same	Different	Same
Centre	8	6	4	2
Between	5	13	7	4
Functional	19	13	18	24

A chi-squared test on relatedness and congruence was carried out on categorical placements within the probe trials and found to be significant ($Chi2 = 13.587$, $p < 0.05$). As can be seen in Table 2, functional placements increased in the non-functional condition when previous objects had been functionally related.

Discussion

These results show again that knowledge of object relations affects object placement, consistent with the results of Experiment 1. Additionally, between placements in this experiment were again not the most common placements, suggesting that participants may be selecting from functional and geometric placements, with between placements representing a compromise between these interpretations.

The three-way interaction provides evidence, consistent with the findings from the A-not-B error studies, that the number of previous placements and similarity of trials both affect interpretation and associated placements on probe trials. This suggests a dynamic interaction between amount of prior use when switching between functional and geometric usage of spatial prepositions, and suggests that one becomes habituated to a particular use of language in the short term.

This view is also supported by the increased functional placements of non-functionally related objects after functional priming with functionally related objects. The prior action and perception of function has caused an increase of novel functional interpretation of spatial language.

General Discussion

The findings of these experiments suggest that, although functional knowledge of objects, geometric knowledge, and general knowledge about the world are used in comprehension of spatial prepositions, the previous actions and perceptions of similar tasks also inform comprehension.

The dynamic systems theory is a useful framework when analyzing this problem, as it allows for comprehension as an on-going process that is continuously informed by perception, action, memory, and the language used. Short term memory of object usage may override the long term knowledge of object usage in the case of novel combinations of objects, such as a tube of oil paint and a toothbrush, allowing novel interactions to be discovered and context specific meanings to be learnt. The processes by which this happens can be described as a time dependent system, where the output is determined through combination of a number of subsystems combine to resolve an ambiguous linguistic problem, where the state of the subsystems is dependent on the preceding information provided to it. Within each subsystem, attractors such as the attractor at position A within the dynamic model of the A not B error (Smith and Thelen, 2003) can be created by prior perception or goal demands, and cause an undue influence on later judgments. Geometric and functional interpretations of meaning could be seen as attractors in a dynamic system, which can be reinforced by context, or combined where insufficient information exists to produce between placements.

If one follows this line of investigation, the necessity of using between subject designs, traditionally regarded as less powerful than within subject designs, becomes clear in order to unpack the time course of meaning construction situated in an unfolding context. We are currently investigating other contextual switches between prime and probe trials using this methodology.

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