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*Sources of Object-Specific Effects in Representational Momentum **

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Sources of Object-Specific Effects in Representational Momentum

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In this study we explore the sources of object-specific effects in representational momentum (RM). "Object-specific effects" refers to the elicitation of different patterns of RM by different objects. We examined whether object-specific effects could be produced by an object's conceptual context, visual features, or their interaction. The conceptual context was composed of the object's label with, in some cases, a description of the object, plus experimental trials requiring the participant to identify the object. In addition, we examined whether the contribution of visual features to object-specific effects came from one particular visual feature previously linked to RM (pointedness), or from the object's overall appearance. Our results show that generally, the stimulus' overall appearance must be consistent with its conceptual context for related conceptual knowledge to produce object-specific RM effects. These experiments therefore provide evidence that knowledge particular to an object, or its category, unconsciously affects mental transformations.

Key Words: Representational momentum, object recognition, perception

1 Object-Specific Effects in RM

In their seminal work, Freyd and Finke (1984) presented participants with a series of snapshots of a stimulus at different points along its trajectory. This technique produced an unconscious mental transformation of the stimulus' mental representation that corresponded to an extension of the stimulus' trajectory. This mental transformation has been referred to as the "memory shift" (e.g. Finke, Freyd, & Shyi, 1986; Freyd & Finke, 1985). Because the memory shift reflected a physical object's tendency to continue moving along its trajectory, this newly discovered psychological phenomenon was termed "representational momentum" (RM; Freyd & Finke, 1984).

Following in the tradition of Shepard and colleagues (1981, 1984; Shepard & Cooper, 1982), most early RM research focused on this analogy between the psychological and the physical (see Hubbard, 1995b for a review). The working hypothesis in this research tradition is that environmental or physical invariants or universals, such as the laws of physics, have been internalized into the representational system as psychological invariants (Hubbard, 1995b, 1999; Shepard, 1981, 1984, 1994). It is these psychological invariants that cause mental transformations to correspond to physical phenomena. The hallmark of an invariant is that it applies to every mental transformation, regardless of personal knowledge of, or experience with, the particular object that is represented.

In contrast to an invariant, an object-specific constraint affects transformations of representations of only a particular type of object. For instance, the knowledge that a rocket goes up is an object-specific constraint in that it only applies to transformations of rocket representations. This constraint is irrelevant when representing a different type of object.

Object-specific *effects* are characterized by differences in mental transformations as a function of the particular type of object represented. Object-specific effects are the natural manifestation of object-specific constraints, but they can also be produced by invariants. Consequently, object-specific *effects* provide evidence for object-specific *constraints* only if there is no confound related to an invariant. Typically, the confounding factor will be related to a law of physics (such as momentum) and unrelated to an object's category or identity. For example, the finding that stimuli with different implied velocities will produce different memory shifts is attributed to the invariant of momentum

(Freyd & Finke, 1985), not to object-specific constraints. An example of object-specific constraints producing object-specific effects is provided by the finding that the memory shift induced by a rocket stimulus was greater than the memory shift induced by a weight stimulus, when implied motion was upward (Reed & Vinson, 1996). Control conditions ensured that this difference in memory shifts could not be fully explained through the action of invariants. (However, as we discuss later, there may have been an interaction between pointedness, which can be related to an invariant, and typical motion.) Reed and Vinson attributed these findings to the participants' pre-existing knowledge that rockets typically move upward. Typical motion is an object-specific constraint because it is a property unique to an object or object category, unlike, for instance, velocity. In sum, before ascribing object-specific effects to object-specific constraints one must ensure that there is no uncontrolled factor that can be related to an invariant.

In this paper we investigate the possible sources of Reed and Vinson's (1996) object-specific effects, while considering whether these sources are invariants or object-specific constraints. Specifically, we examined whether the conceptual context in which the stimulus is presented, the stimulus' visual features, or their interaction produce object-specific effects. The conceptual context conveyed information about typical motion. The visual features we examined were prototypicality and pointedness. By "prototypicality", we mean the extent to which an object is a good exemplar of its category. For example, a robin is a good exemplar of the bird category, so it is prototypical. Pointedness is the extent to which the stimulus points in one of the directions of implied motion.

We selected pointedness as a candidate source because it has been implicated in many experiments showing object-specific effects in RM. Pointedness can be related to the psychological invariant of representational friction (Hubbard, 1995a, b) in the following way. On objects like cars and aeroplanes, a pointed front will reduce drag, easing forward motion. Similarly, one could expect a pointed stimulus to produce less psychological drag when moving in its pointing direction. Consequently, memory shifts produced by implied motion in the pointing direction should be larger than shifts produced by implied motion in the opposite direction. In addition, these former memory shifts should lengthen with increased pointedness (Nagai & Yagi, 2001).

A review of the literature suggests a combination of pointedness and strong typical motion is necessary to produce object-specific RM effects. Freyd and Pantzer (1995) showed an object-specific effect with an arrow stimulus pointing in its direction of typical motion-forward. The object-specific effect manifested itself as a greater memory shift for forward implied motion than for backward implied motion. Two other studies employed pointed control stimuli in addition to stimuli pointing in their directions of typical motion (Freyd & Miller, 1992; Reed & Vinson, 1996). In these studies, only the stimuli with typical motions produced object-specific effects, suggesting that both typical motion and pointedness are necessary to produce object-specific effects. However, in Nagai and Yagi's (2001) experiments, pointedness, but not typical motion, was responsible for object-specific effects. Nagai and Yagi suggested that their use of apparent motion rather than implied motion reduced the impact of conceptual knowledge about typical motion on the memory shift. In sum, it seems that pointedness at least contributes to object-specific effects. Given the design of the experiments however, it remains to be seen whether typical motion on its own can produce object-specific effects within an implied motion paradigm.

It is also important to note that all but one of the pointed/typical motion stimuli used in the above experiments were prototypical: arrow (Freyd & Pantzer, 1995), bird (Freyd & Miller, 1992), rocket (Reed & Vinson, 1996), and pointed Concorde-like aeroplane (Nagai & Yagi, 2001). Moreover, pointedness appears to have contributed to this prototypicality: Arrows have pointed front ends, birds have pointed beaks, rockets have pointed tops, and the Concorde has a pointed nose. Here, we raise the possibility that a prototypical stimulus is more likely to elicit knowledge of the typical motion of the object it depicts. Indeed, in general, more prototypical objects generate more inferences than less prototypical ones (Rosch, Mervis, Gray, Johnson, & Boyes-Braem, 1976). Consequently, via the elicitation of typical motion knowledge, a prototypical stimulus is more likely to affect the memory shift. An effect of prototypicality therefore implies the operation of an object-specific constraint (typical motion). The pointedness/prototypicality confound mentioned previously raises the question of whether pointedness contributes to object-specific effects by increasing prototypicality or by reducing representational drag.[1] The distinction is important because prototypicality implicates an object-specific constraint, while drag is a manifestation of the friction invariant.

In the following experiments, we also constructed conceptual contexts to activate conceptual knowledge about typical motion independently of stimulus prototypicality or pointedness. The conceptual context was composed of a stimulus label and, in some cases, a description provided in the instructions, plus experimental trials requiring the participant to identify the stimulus as labelled in the instructions. Our conceptual context manipulation was motivated by findings of cueing effects in RM. The cue constituted a conceptual context eliciting expectations about the stimulus' direction of motion. These expectations then affected the memory shift (Hubbard, 1994).

To summarize, we investigated various interactions of three possible sources of object-specific effects: pointedness, prototypicality, and conceptual context. Prototypicality and conceptual context are both related to the object-specific constraint of typical motion, whereas pointedness, when acting independently of prototypicality, implicates the invariant of friction. In the first experiment, we assess the ability of conceptual context to elicit object-specific effects with a non-prototypical and unpointed stimulus. In our second experiment we test the hypothesis that pointedness is responsible for object-specific effects. As already mentioned, pointedness, prototypicality, and typical motion have often been confounded. In our final experiment we examine whether pointedness is necessary to produce object-specific effects with a prototypical stimulus that has a strong typical motion.

2 Experiment 1: The Power of Conceptual Context

In this experiment we examined whether conceptual context alone produces rocket-like object-specific RM effects. If conceptual knowledge is the sole source of object-specific effects (Reed & Vinson, 1996), then a conceptual context activating the participants' knowledge of typical rocket motion should produce rocket-like object-specific effects. To test this hypothesis we created stimuli and conceptual contexts to manipulate the pointedness, prototypicality, and conceptual context factors as specified in Table 1 and Figure 1A.

Table 1

Manipulations of Pointedness, Prototypicality, and Conceptual Context in Experiment 1

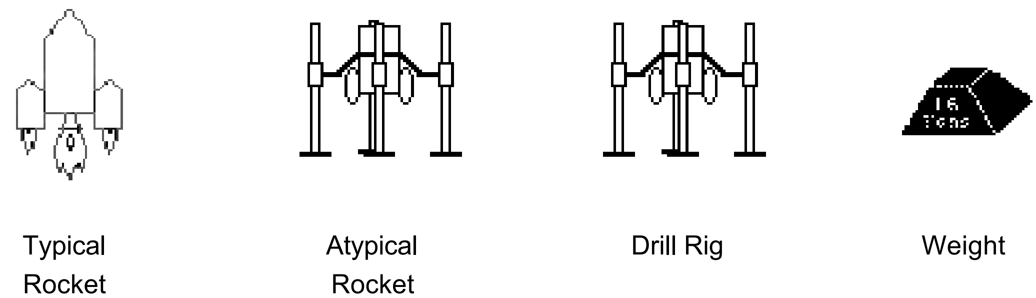
Factor / Stimulus	Prototypical rocket	Drill rig	Atypical rocket
Pointedness	Up	None	None
Prototypicality	For rockets	Somewhat, for drill rigs	Not for rockets. More prototypical for drill rigs
Direction of typical motion suggested by prototypicality	Up	None	None
Conceptual context	For rockets	For drill rigs	For rockets
Direction of typical motion suggested by conceptual context	Up	None	Up

The experiment contained three between-subjects groups that differed only on the basis of their test stimulus. In the discussion to follow, each group is referred to by its particular test stimulus. For instance, the test stimulus for the

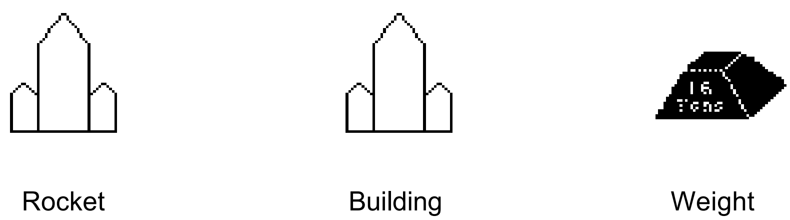
[1] Nagai and Yagi (2001) employed four stimuli in their third experiment: a pointed Concorde-like aeroplane, an unpointed propeller plane, a pointed carrot, and an unpointed signpost. No effects of typical motion were detected despite the prototypicality of the two aeroplanes — the two stimuli with typical motions.

Figure 1

A. Stimuli for Experiment 1



B. Stimuli for Experiment 2



C. Stimuli for Experiment 3

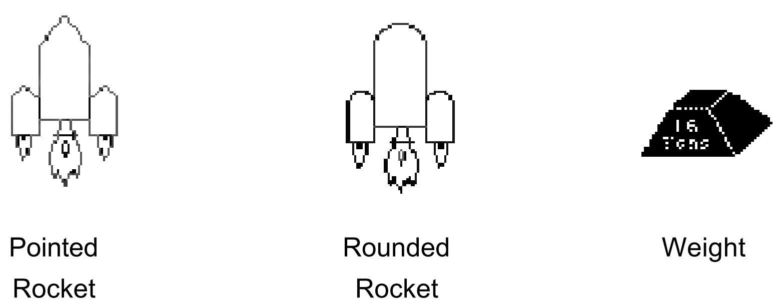


Figure 1: Stimuli for Experiments 1, 2, and 3. A) Experiment 1: The weight and rocket were taken from Reed & Vinson (1996). The third stimulus was alternately labelled "rocket" or "drill rig" depending on the group to which the participant belonged. In the paper, we refer to this stimulus as the "drill rig" or "atypical rocket." B) Experiment 2: The weight was taken from the first experiment. The other stimulus was alternately labelled "rocket" or "building" depending on the group to which the participant belonged. C) Experiment 3: The pointed rocket is from Experiment 1. The rounded rocket was constructed from the pointed rocket by rounding its points.

prototypical rocket group was the prototypical rocket (see Figure 1A). This rocket's prototypicality was consistent with its conceptual context provided by its label in the instructions (“rocket”) and identification trials requiring the participant to recognize the stimulus. The atypical rocket group's test stimulus had visual features that are not typically associated with rockets, but its conceptual context was designed to elicit conceptual knowledge of rockets. The atypical rocket's conceptual context consisted of a "rocket" label, a fictional description of the atypical rocket’s function (see Appendix), and identification trials. The description was intended to make the label more believable and memorable. The drill rig group's test stimulus had the same visual features as the atypical rocket, but its conceptual context gave it the function of an offshore drilling platform (see Appendix). Since it looked somewhat like a drill rig, it was somewhat prototypical for the drill rig category of objects.

Each group was exposed to trials containing their test stimulus as well as trials containing a baseline weight stimulus. The memory shifts induced by the weight were used as a baseline against which the memory shifts induced by the test stimulus were compared. Individual trials consisted of a particular combination of a stimulus, weight, or test (as a function of subject group), and direction of implied motion, upward or downward. Over the course of an experimental session, each participant was exposed to trials implementing all four stimulus/direction of implied motion combinations, i.e., test upward, test downward, weight upward, and weight downward. Comparing the memory shifts induced by these four types of trials revealed the test stimulus' object-specific effects.

Based on Reed and Vinson's (1996) findings, we expected rocket-like object-specific effects for the prototypical rocket group. These effects would take the form of a stimulus by direction of implied motion interaction showing a greater memory shift for the prototypical rocket than for the weight for upward implied motion, and, possibly, a greater memory shift for the weight for downward implied motion. If conceptual context alone were sufficient to produce object-specific effects, we would expect to find this same interaction for the atypical rocket group. However, if object-specific effects rely on a consistent combination of visual features and conceptual context then this object-specific interaction would only be found for the prototypical rocket group. Because a drill rig does not have an upward typical motion, the data from this control group reveals whether the drill rig/atypical rocket stimulus’ visual appearance, or shape, induced any object-specific effects.

2.1 Method

2.1.1 Participants

Thirty-nine Carnegie Mellon University undergraduates and ten members of the CMU community received either course credit or payment for their participation. All participants were naïve as to the purposes of the experiment.

2.1.2 Stimuli and Apparatus

Three line drawings were used as stimuli in this experiment: an atypical rocket/drill rig (18.5 mm X 20.6 mm)[2], a prototypical rocket (13.4 mm X 23.0 mm), and a ton weight (22.3 mm X 12 mm) (Figure 1A). The prototypical rocket and weight were the same stimuli used in Reed and Vinson’s (1996) Experiment 2. Depending on the group to which the participant belonged, the instructions also furnished descriptions of some of the stimuli (see Appendix).

There were two types of trials: memory trials and identification trials. Memory trials were designed to probe the participant's memory of the stimulus position. They conformed to the general RM experimental paradigm described by Freyd and Finke (1984). Identification trials instructed the participant to identify the stimulus. Both trial types used the same inducing sequence, differing only in the presentation of the probe and the participant's response. Consequently, participants could not know which type of trial they were experiencing until the response was required. This encouraged participants to attend to the stimulus' identity from the start of any trial so that, if that trial were an identification trial, they could respond correctly. Identification trials also reactivated the participants' conceptual knowledge of the stimulus object.

All trials consisted of a sequence of a "Ready?" prompt, displayed for 1000 ms, followed by five frames. The first four frames formed the inducing sequence, each frame depicting the

[2] All sizes reported in this paper were measured directly on the computer screen, at a distance of 0 mm from the screen.

same stimulus 15.4 mm higher or lower than in the previous frame, depending on whether the implied motion direction was upward or downward. The fourth frame was the memory frame, showing the stimulus position to be remembered. The content of the fifth frame depended on whether the trial was a memory or identification trial. For the memory trials, the fifth frame, the test frame, displayed the probe stimulus until the participant responded. The probe stimulus was displayed in one of nine positions in relation to the memory frame stimulus' position: one position was the same as the memory frame stimulus', four positions were further in the direction of implied motion, and four positions were further in the direction opposite to implied motion. These probe positions were measured in relation to the memory frame stimulus' position. For the identification trials, the fifth frame showed a textual prompt asking participants to press one of two keys to identify the stimulus shown in the four previous frames. Note that the stimulus was not displayed in this frame.

The temporal parameters were identical for both trial types. In each of the first four frames, the stimulus was displayed for 250 ms and followed by a 250 ms Inter-Stimulus Interval (ISI). The retention interval between the fourth and fifth frames also lasted 250 ms. The fifth frame display remained on-screen until the participant responded. These temporal parameters did not lead to the perception of apparent motion and permitted the participants to recognize the stimulus in the first frame.

In half of the trials, the inducing sequence portrayed downward implied motion, while in the other half, the inducing sequence showed upward implied motion. When the direction was *up*, the memory frame was positioned *above* the centre of the screen, and when the direction was *down*, the memory frame was positioned *below* the centre of the screen. In addition, the inducing sequences were positioned such that each memory frame stimulus could be displayed at one of three distances from the centre of the screen (18.9, 22.3, or 25.7 mm, as measured on the screen itself). The goal of this manipulation was to prevent participants from simply fixating the centre of the screen throughout the experiment.

This experiment was run on Macintosh® Classic® and Classic II® computers, using the PsyScope© application (Cohen, MacWhinney, Flatt, & Provost, 1993).

2.1.3 Design and Procedure

The design for the memory trials was a factorial combination of one between-subjects factor and four within-subjects factors: 3 (group, between) x 2 (stimulus: weight or test — prototypical rocket, atypical rocket, or drill rig depending on group) x 2 (directions of implied motion: upward or downward) x 9 (probe stimulus positions: ±7.9, ±6.2, ±3.8, ±2.1, 0 mm) x 3 (memory frame positions: 18.9, 22.3, 25.7 mm). For identification trials, there was one between-subjects factor and three within-subjects factors: 3 (group, between) x 2 (stimulus: weight or test — prototypical rocket, atypical rocket, or drill rig depending on group) x 2 (direction of implied motion) x 3 (memory frame position).

Participants were seated in front of a computer in a well-lit room. The distance from the screen to the edge of the table at which the participants were seated was 37.0 cm. However, participants were free to adjust their seating position and distance. They read the instructions and viewed a picture of the labelled stimuli appropriate for their group. The instructions explained the task and the difference between memory and identification trials. For memory trials, the participants were instructed to respond as accurately and as quickly as possible by pressing a key to indicate whether the memory and test frame stimuli were displayed in the same position. Similarly, a key press was used to identify the stimulus in an identification trial. To facilitate the participants' responding, a template covered all but the necessary keys.

Participants received 25 practice trials with feedback. The practice set included both memory and identification trials. Following the practice trials, 264 memory and identification trials, without feedback, were presented. All conditions were presented once, in random order, and then presented again, in random order. The experimental session lasted approximately 45 minutes.

2.2 Results

Participants demonstrated accurate performance on both identification trials (mean proportion of correct responses = 0.99, lowest score 0.90) and memory trials (mean proportion of correct responses = 0.77, lowest score = 0.62). Consequently, no participant was eliminated from the analyses. To eliminate trials in which participants were not paying attention, trials in which response times (RTs) were less than 150 ms or more than 3000 ms were trimmed away. Then, trials with RTs beyond three standard deviations of the participant's individual mean were trimmed away. In total, only 2.2% of the data were removed.

We estimated the memory shift with the proportion of responses indicating that the memory and test frame stimuli were perceived to be in the same position. We refer to such responses as *"same" responses*. We first calculated the proportion of "same" responses for each probe position, thus producing a distribution of "same" responses across all positions. Note that the probe positions were signed such that probe positions inconsistent with the direction of implied motion were negative, while the consistent ones were positive. We then calculated a weighted mean of each "same" response distribution. A positive weighted mean indicated a memory shift corresponding to a continuation of the implied trajectory, thus signalling that RM occurred. The weighted means were obtained in the following way. For each probe position, the product of the proportion of "same" responses and its corresponding probe position was calculated. These products were then summed and this sum was divided by the sum of the "same" response proportions (see also Nagai and Yagi, 2001). For each participant, a weighted mean was calculated in this manner for each stimulus by direction of implied motion condition.

To directly address the hypothesized object-specific effects in each subject group, we conducted planned (a priori) comparisons (Figure 2). Three orthogonal planned comparisons (Ferguson, 1981) determined whether the test stimulus produced a greater memory shift than the weight for upward implied motion and/or a smaller memory shift than the weight for downward implied motion.[3] Only the prototypical rocket group showed a significant effect, $F(1,46) = 7.48$, $p < 0.01$. No significant effects were found for similar planned comparisons for the atypical rocket group, $F(1, 46) < 1$, ns, and the drill rig group, $F(1,46) < 1$, ns. An additional planned comparison shows a significant difference between the size of the prototypical rocket group's object-specific effect and the average size of the two other groups' object-specific effects,[4] $F(1,46) = 4.02$, $p = 0.05$.

Figure 2

Memory Shifts by Direction of Implied Motion for Each Stimulus Pair in Experiment 1

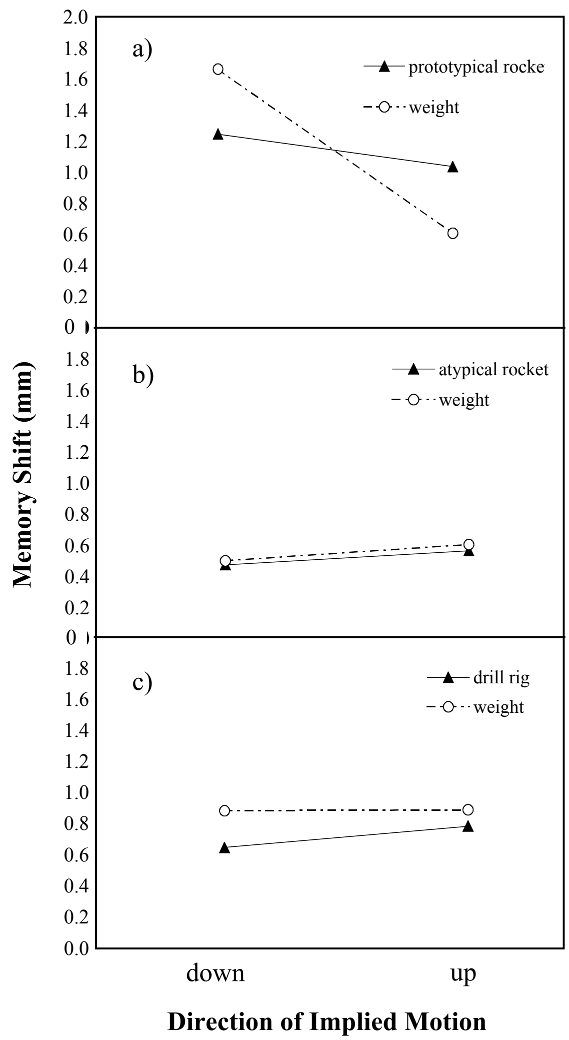


Figure 2: Stimulus by implied motion interactions showing object-specific effects for each group in Experiment 1: (a) prototypical rocket group, (b) atypical rocket group, (c) drill rig group. Only the prototypical rocket group (a) shows rocket-like object-specific effects.

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[3] The three orthogonal planned comparisons were based on the equation: [test(up) - weight(up)] > [test(down) - weight(down)], in which each term designates a particular stimulus by direction of implied motion cell mean.

[4] This comparison was not orthogonal to the previous three. It tested the following inequality: $rkt_{fx} > (atyp\ rkt_{fx} + drill\ rig_{fx})/2$, where "fx" denotes the object-specific effects tested in the previous planned comparisons.

Another set of three orthogonal planned comparisons (Ferguson, 1981) established that the patterns of weight memory shifts differed across groups. For the prototypical rocket group, the difference between the weight's upward and downward implied motion memory shifts was highly significant, $F(1,46) = 23.32$, $p < 0.001$. In contrast, for both the drill rig and atypical rocket groups, the corresponding comparisons were not significant, $F(1,46) < 1$, ns (see Figure 2).

2.3 Discussion

In this experiment, object-specific effects manifested themselves as stimulus (test/weight) by direction of implied motion interactions. Such an interaction was found for the prototypical rocket group but not for the atypical rocket or drill rig groups (Figure 2). Since the atypical rocket group did not show rocket-like object-specific effects, we conclude that conceptual context alone is insufficient to produce object-specific effects in RM. Thus, it appears that the object-specific RM effects found by Reed and Vinson (1996) are not purely conceptual. In addition, some aspect of the stimulus' visual features (perhaps pointedness or prototypicality) is necessary to produce object-specific effects.

The data also show what have been called set effects (Halpern & Kelly, 1993): The memory shift induced by one stimulus depends on which other stimuli are presented during the experiment. In this experiment, the memory shift induced by the weight depended on the stimulus with which it was paired: When paired with the prototypical rocket, the weight showed drastically different effects for upward and downward implied motion, but this was not so when the weight was paired with the drill rig or the atypical rocket. Such set effects may result from a global conceptual context induced by all the stimuli shown in an experiment. In this experiment, the contrast in the typical motions of weights (which tend to fall) and rockets (which tend to rise) may have increased the salience of these typical motions for the prototypical rocket group, and as a result, may have also increased the effects of typical motion on RM. As set effects are not the focus of this paper, this explanation remains to be tested.

It is important to also note one technical point. When conducting experiments with conceptual effects there is an issue whether the results are due to task demand characteristics or experimenter expectancies (see e.g., Farah, 1988; Jolicoeur & Kosslyn, 1985). The task demand characteristics of the RM experimental paradigm work against the production of RM, if the participants respect the instructions to respond accurately (Finke & Freyd, 1989). The danger lies in the participants inducing the purpose of the experiment from the instructions and trial structure, ignoring the response guidelines set forth in the instructions, and tailoring their responses to intentionally produce the sought-after object-specific effects. However, a comparison of prototypical rocket group's data with the atypical rocket group's data shows that participants were not intentionally producing rocket-like object-specific responses. Although both groups were exposed to the same instructions and the same experimenter biases (both groups were expected to show rocket-like object-specific effects), they produced different response patterns. These differences must have resulted from the stimulus differences.

Table 2

Manipulations of Pointedness, Prototypicality, and Conceptual Context in Experiment 2

Stimulus / Factor	Rocket	Building
Pointedness	Up	Up
Prototypicality	Low (for rockets)	Mid to high (for buildings)
Direction of typical motion suggested by prototypicality	Up	None (immobile)
Conceptual context	For rockets	For buildings
Direction of typical motion suggested by conceptual context	Up	None (immobile)

3 Experiment 2: The Interaction of Conceptual Context and Visual Features

In Experiment 2, we examined whether object-specific effects could be influenced by the conceptual context as long as it was supported by the stimulus' visual features. Specifically, we investigated whether the object-specific effects seen with the rocket stimulus would generalize to a visually identical, pointed, stimulus with a conceptual context suggesting a typical motion that was not rocket-like. Here, as in Experiment 1, a baseline weight stimulus was paired with a test stimulus labelled either as “building” or as “rocket,” depending on the group to which the participant belonged (Table 2, Figure 1B). If pointedness alone could produce rocket-like object-specific effects, then both subject groups should show the same rocket-like pattern of data. However, if conceptual context supported by prototypicality drives object-specific effects, then we should find an object-specific effect only for the “rocket” group.

3.1 Method

3.1.1 Participants

Forty-eight Carnegie Mellon University undergraduates and nine members of the CMU community received either course credit or payment for their participation. All participants were naïve as to the purposes of the experiment, and none had participated in Experiment 1. In addition, 25 University of Denver undergraduates completed a prototypicality questionnaire for extra credit.

3.1.2 Stimuli and Apparatus

Two line drawings were used as stimuli in this experiment: a building/rocket test stimulus (13.4 mm X 16.1 mm) and the weight from Experiment 1 (see Figure 1B). The conceptual context consisted of the labels “building” or “rocket”, their associated descriptions, and identification trials. The “rocket” stimulus description stated that the main section of the rocket was in the middle with two rocket boosters at the sides. The “building” stimulus description stated that participants were looking at the front of the building with the main section in the middle, and two annexes at the sides.

For both memory and identification trials, the inducing sequence was the same as in Experiment 1. Only the test frame in the identification trials differed between the groups, allowing the participant to identify the test stimulus as either a building or rocket, depending on the participant's group.

To obtain an independent rating of the test stimulus' prototypicality, we had a separate group of participants fill out a questionnaire by labelling a crescent line drawing, the test stimulus, and an abstract line drawing. Each questionnaire item was presented on a separate page in counterbalanced order.

The apparatus was the same as that used in Experiment 1.

3.1.3 Design and Procedure

The design for this experiment was identical to that of Experiment 1, except that the between-subjects factor (group) had only two levels: the “building” group and the “rocket” group. The “building” group participants saw the building/rocket stimulus *labelled* as a building in the instructions. In contrast, the “rocket” group saw the building/rocket stimulus *labelled* as a rocket in the instructions.

The procedure was the same as that used in Experiment 1, except for those sections of the instructions that referred to the test stimulus’ identity, and the manipulation check conducted just before debriefing. The manipulation check consisted in determining whether the test stimulus reminded the participant of any other object during the course of the experiment. Participants who indicated that the test stimulus had reminded them of another object were characterized as unconvinced by the conceptual context provided. Since the typical motion of these other objects could have affected the memory shift, we examined the data from the unconvinced participants separately.

3.2 Results

We used the results from the prototypicality questionnaire and the manipulation check to characterize the prototypicality of the test stimulus as a rocket and as a building. All 25 questionnaire respondents labelled the test stimulus a building. However, the manipulation check revealed that nine "building" group participants thought the test stimulus looked like a rocket. Consequently, we characterized the test stimulus as having a mid-to-high level of prototypicality as a building, and a low level of prototypicality for rockets (see Table 2). Note that the rocket prototypicality rating is higher than the prototypicality rating for the Experiment 1 atypical rocket.

Performance on the identification trials indicated that all participants were motivated to respond accurately. The lowest proportion of correct answers in the identification trials was 0.85 and the mean was 0.98. Two participants' scores were more than three standard deviations below the mean, but even so, their scores were quite high (0.88 and 0.85). All scores were well above chance (chance = 0.5). The lowest proportion correct score on the memory trials was 0.56 and the mean was 0.77. No participant was eliminated on the basis of identification or memory trial performance.

Figure 3

Memory Shifts by Direction of Implied Motion for Each Stimulus Pair in Experiment 2

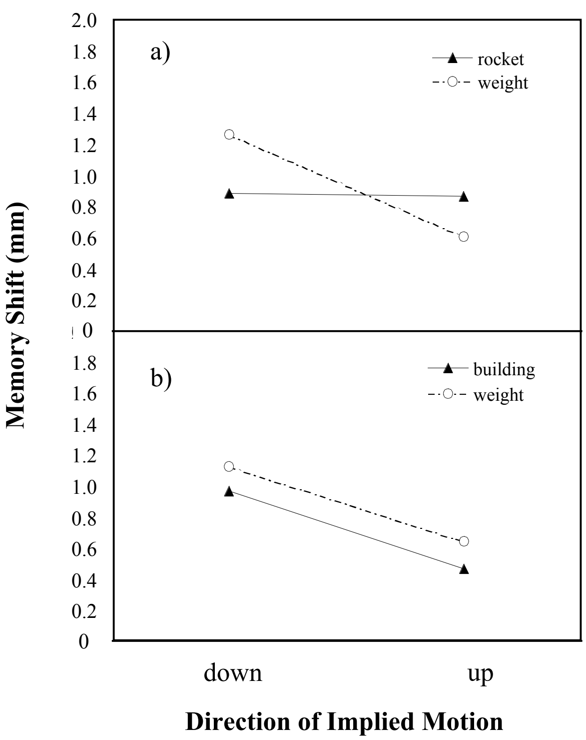

Figure 3: Stimulus by implied motion interactions for Experiment 2: (a) rocket group, (b) building group. The object-specific effects for each group are given by the stimulus by implied motion interaction. Only the "rocket" group (a) shows rocket-like object-specific effects.

The memory trial data were trimmed (2.3% of the data were eliminated) and analysed as in Experiment 1. All participants who indicated that the test stimulus reminded them of another object were characterized as unconvinced by the conceptual context (n = 16). Their data were examined separately and did not show any object-specific effects.

Using the data from the remaining 41 convinced participants, orthogonal planned comparisons for directional, object-specific interactions were conducted within each group, based on the same equation used in Experiment 1. The comparison was significant for the "rocket" group, $F(1,39) = 7.00$, $p < .05$, but not for the "building" group, $F(1,39) < 1$, ns. Thus, the "rocket" group showed the characteristic rocket-like object-specific effects but the "building" group did not (Figure 3).

3.3 Discussion

The data from the convinced participants are quite clear (Figure 3). Only the “rocket” group showed rocket-like object-specific effects. Moreover, the “building” and weight stimuli did not elicit different memory shift patterns. In particular, the pointed “building” did not show a greater memory shift for upward implied motion than the weight. In short, despite having identical visual features, the “rocket” and “building” stimuli produced different results. Our prototypicality questionnaire indicated that the test stimulus was of low prototypicality for the rocket category. Nonetheless, the conceptual context was strong enough to elicit rocket-like object-specific effects. Taking into account the results from the first experiment, it seems that conceptual context will determine the object-specific effects as long as it is at least minimally supported by prototypicality, and perhaps also by pointedness. (Note that the "rocket" test stimulus *was* pointed.) However, since the "building" was also pointed but did not show rocket-like effects, we conclude that pointedness alone is insufficient to produce rocket-like object-specific effects. It remains to be seen whether conceptual context can determine the object-specific effects when it is supported by prototypicality only, or whether pointedness is also necessary for these effects to occur. We investigate this question in our third experiment.

4 Experiment 3: The Influence of Pointedness

In the first two experiments, we found that visual features and conceptual context must work together, or support each other, to produce the object-specific interaction. However, as with most of the previous experiments showing object-specific effects, all of our stimuli producing object-specific effects have been pointed in the direction of typical motion. Furthermore, the pointed visual feature contributed to their prototypicality. Consequently, we do not know what aspects of a stimulus' visual features are important in producing object-specific effects. Is the effect influenced most by a particular visual feature, namely pointedness, or by the object’s overall prototypical appearance? Although several studies have examined the effects of pointedness on motion perception and representation, it is not clear the extent to which cognitive interpretations of the stimuli contributed to the effects (Attneave, 1971; Freyd & Panzer, 1995; McBeath, Morikawa, & Kaiser, 1992; Palmer, 1980; Palmer & Bucher, 1982; Reed & Vinson, 1996). Here we address whether pointedness is necessary, in addition to the proper conceptual context and prototypicality, to produce object-specific RM effects.

We compared memory shift patterns for two prototypical rockets that differed only in their tops: One was rounded and one was pointed (see Figure 1C). Moreover, we provided rocket conceptual contexts for both stimuli by labelling them both "rocket" in the instructions (Table 3). Following our designs from the previous experiments, we ran two between-subject groups, each group seeing one test stimulus, either the rounded rocket or the pointed rocket, paired with the baseline weight. If pointedness were an important contributor to object-specific effects, then the stimulus by direction of implied motion interaction should occur only for the pointed rocket group.

4.1 Method

4.1.1 Participants

Twenty-eight University of Denver undergraduates and graduate students either received course credit or volunteered to participate. An additional 25 University of Denver undergraduates received extra course credit to answer the prototypicality and pointedness questionnaire. All participants were naïve as to the purposes of the experiment. None had participated in the previous experiments.

4.1.2 Stimuli and Apparatus

Three line drawings were used as stimuli in this experiment: a pointed prototypical rocket and the weight, both from Experiment 1, and a rounded prototypical rocket (see Figure 1C). The rounded rocket was constructed from the pointed rocket stimulus by rounding the pointed ends. (Both rockets measured 13.4 mm X 23.0 mm.)

For both memory and identification trials, the inducing sequence was the same as in prior experiments. For the test frames in the memory trials however, the probe positions were changed in an attempt to eliminate the tails of the "same" response distributions. The stimulus identification prompts were identical to the prototypical rocket condition from Experiment 1.

To get an independent rating of our stimuli’s prototypicality and pointedness, we asked a separate group of participants to complete a questionnaire. In a counterbalanced order, the questionnaire presented the two rockets, and asked respondents to first label and then rate each stimulus for prototypicality and for

Table 3

Manipulations of Pointedness, Prototypicality, and Conceptual Context in Experiment 3

Stimulus **Factor**	**Pointed rocket**	**Rounded rocket**
Pointedness	Up	None
Prototypicality	High (for rockets)	High (for rockets)
Direction of typical motion suggested by prototypicality	Up	Up
Conceptual context	For rockets	For rockets
Direction of typical motion suggested by conceptual context	Up	Up

pointedness on a scale from 1 to a maximum of 10.

The apparatus was the same as that used in Experiments 1 and 2.

4.1.3 Design and Procedure

The design for this experiment was identical to that of Experiment 1, except that the between-subjects factor (group) had only two levels, the pointed rocket group and the rounded rocket group, and the probe positions were changed to 0 mm, ± 1.1 mm, ± 2.1 mm, ±2.8 mm, and ±3.8 mm . The procedure was the same as that used in Experiment 1 in the prototypical rocket condition.

4.2 Results

In response to our questionnaire, all but one participant (24/25) labelled both the pointed and rounded rockets as "rocket". The pointed rocket (mean = 7.92) was rated as only slightly more prototypical than the rounded rocket (mean = 6.84). In contrast, the pointed rocket (mean = 7.16) was rated as much more pointed than the rounded rocket (mean = 2.60). The ratings in Table 3 are based on these data.

The memory trial data were trimmed (less than 2.2% of the data were eliminated) and weighted means were calculated as in Experiment 1. Performance on the identification trials indicates that all participants responded accurately (mean proportion correct = 0.97, lowest score = 0.84). Participants also showed reasonable accuracy for memory trials (mean proportion correct = 0.75, lowest score = 0.60). No participant was eliminated based on identification or memory trial performance.

Directional, orthogonal planned comparisons were conducted using the same equation as in Experiments 1 and 2. They showed a significant stimulus by direction of implied motion interaction for the pointed rocket, $F(1, 26) = 5.41$, $p < 0.05$, as well as for the rounded rocket, $F(1, 26) = 7.43$, $p < 0.05$. Comparisons for rocket type (pointed vs. rounded) and direction of implied motion showed no stimulus effect for upward implied motion, $F(1, 26) = 3.20$, ns, demonstrating that the pointed rocket did not produce a significantly greater upward memory shift than the rounded rocket (Figure 4).

4.3 Discussion

Since we found similar object-specific effects for both the pointed and rounded rockets, we conclude that the overall prototypical appearance of the stimulus, rather than the single feature of pointedness, produces the rocket-like object-specific effects.

Figure 4

Memory Shifts by Direction of Implied Motion for Each Stimulus Pair in Experiment 3

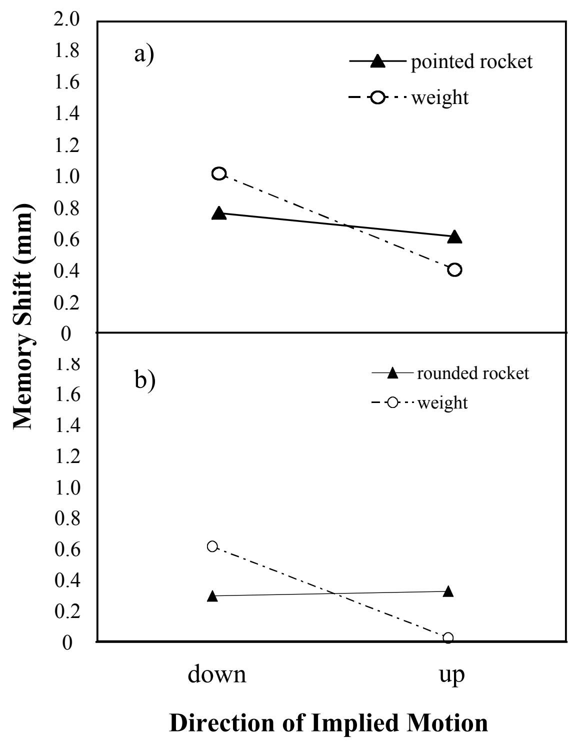

Figure 4: Stimulus by implied motion interactions for Experiment 3: (a) pointed rocket group, (b) rounded rocket group. The object-specific effects for each group are given by the stimulus by implied motion interaction. Both types of rockets (a and b) produced rocket-like object-specific effects.

These results differ from Nagai and Yagi (2001) in that they found pointedness, but not typical motion, to be the source of object-specific effects. This difference in findings may be explained by two methodological differences: our use of implied motion in contrast to Nagai and Yagi's use of apparent motion, and our use of a benchmark weight stimulus in detecting object-specific effects. Nagai and Yagi proposed that apparent motion displays are more likely to activate feature detectors than implied motion displays, and as a result, produce feature-based object-specific effects. In addition, they suggest that feature-based effects may override or overshadow cognitive effects based on typical motion. Moreover, in contrast to Nagai and Yagi, we assessed object-specific effects relative to a baseline. Specifically, we compared the memory shifts induced by a test stimulus (e.g. the atypical rocket) to those induced by the baseline weight. Given that the baseline's memory shifts sometimes varied with the test stimulus with which it was paired (see Figure 2), a baseline assessment method could produce different results than a method involving only direct comparisons between test (non-baseline) stimuli.

In conclusion, we found that prototypicality is more important than pointedness in eliciting object-specific effects. However, in the context of previous findings, our results highlight the need for further research on the relationship between object-specific effects and the display's similarity to real motion.

5 General Discussion

In this study we investigated the sources of object-specific effects on RM. In previous work (Reed & Vinson, 1996), we demonstrated that the size of the RM memory shift was related to a stimulus object's typical motion. For instance, stimuli that looked like rockets elicited greater memory shifts for upward implied motion. Because the size of the memory shift was tied to a particular object, we called these effects "object-specific effects". In the current experiments, object-specific effects manifested themselves as stimulus (test/baseline) by direction of implied motion interactions (see e.g. Figure 2, prototypical rocket group). The three experiments in this study, conducted under the RM methodological paradigm described by Freyd and Finke (1984), examined whether object-specific effects could be produced by an object's conceptual context, visual features, or their interaction. Together these experiments demonstrated that object-specific effects are produced when both the stimulus' prototypicality (the extent to which the stimulus object is a good exemplar of a particular category) and its conceptual context correspond to an object with a strong typical motion.

In Experiment 1, we manipulated conceptual context and stimulus prototypicality. We found that conceptual context alone was insufficient to produce object-specific effects consistent with that context, and that some aspect of the stimulus' visual features contributed to producing object-specific effects. In Experiment 2, we again investigated the role of conceptual context, but this time we ensured that the test stimulus' visual features were consistent with two different conceptual contexts. In contrast to the results of Experiment 1, we found that the conceptual context could produce object-specific effects: The stimulus labelled "rocket" produced rocket-like object-specific effects, whereas the same stimulus labelled "building" did not. Moreover, since the "building" was pointed but did not show rocket-like effects, we conclude that pointedness alone is insufficient to produce rocket-like object-specific effects. The findings from Experiments 1 and 2 indicate that conceptual context will determine the object-specific effects as long as it is at least minimally supported by prototypicality and perhaps by pointedness also. Since a single visual stimulus produced different results according to its conceptual context, we can state that the mental transformations taking place in RM are affected by conceptual object-specific constraints, not only invariants. In Experiment 3, we investigated which aspect of the stimulus' visual features, prototypicality or pointedness, was critical in producing object-specific effects by comparing the effects produced by a prototypical rounded rocket to those produced by a prototypical pointed rocket. Since both stimuli produced similar effects, it appears that it is the overall prototypical appearance of the stimulus, rather than the single feature of pointedness, that is necessary to produce rocket-like object-specific effects.

The results presented here largely support Reed and Vinson's (1996) hypothesis that conceptual knowledge affects RM. (Hubbard & Bharucha, 1988, and Ranney, 1989 have also proposed similar ideas.) In Experiment 2, a manipulation of conceptual context affected the memory shift, thus revealing importance of conceptual knowledge. The core of Reed and Vinson's theory of RM rests on the finding that maintaining the object's identity throughout the inducing sequence is important for producing RM (Kelly & Freyd, 1987). This indicates that the identity of the object depicted in each frame is attended to, recognized, and recorded. Reed and Vinson hypothesize that this recognition elicits conceptual knowledge from long-term memory that relates to that object's expected motion in the context of the displayed situations. This information then acts on RM by affecting the memory shift's rate of growth, the point at which it stops growing, or the path it takes.

The present experiments also show that perceptual features, via their contribution to prototypicality, can elicit object-specific knowledge that influences RM. Reed and Vinson (1996) did not deny the role of perceptual features, but they did note that their effects could be overridden by conceptual knowledge. In contrast to this view, Experiment 1 showed that prototypicality could override the conceptual context to determine the effects on RM. Additional research is needed to more precisely describe the relationship between prototypicality and conceptual context.

Our study raises two other issues that require further investigation: stimulus set effects, and the influence of perceived motion quality on various object-specific and invariant effects. Stimulus set effects are evidenced by the effect of a stimulus on the memory shifts induced by *another* stimulus in the same experiment. For example, in Experiment 1 the memory shifts for the baseline weight stimulus differed as a function of the particular test stimulus (prototypical rocket, atypical rocket) with which it was paired (see Figure 2). Halpern and Kelly (1993) detected similar effects. The cause of such set effects remains unclear. We speculate that they may be a manifestation a global conceptual context induced by all the stimuli shown in an experiment. When a stimulus is recognized as a known object, conceptual knowledge associated to that object is recalled. When several stimuli are presented in an experiment, conceptual knowledge related to each stimulus may combine to form the global conceptual context. Just as conceptual knowledge about one stimulus can affect RM, so too may the global conceptual context. For example, in Experiment 1, the contrast in the typical motions of weights (which tend to fall) and rockets (which tend to rise) may have increased the salience of these typical motions to the prototypical rocket group. This increased salience could then be responsible for this group's more extreme weight memory shifts. It remains to be shown whether set effects result from a global context born of the conceptual knowledge elicited by each stimulus.

It has been suggested that the amount of particular types of information contained in a display might affect the mental transformations induced by that display (Vinson, 1995). In particular, displays that appear more similar to real motion may be less sensitive to cognitive effects (Nagai & Yagi, 2001; Shepard, 1984; Vinson, 1995). Nagai and Yagi proposed that apparent motion displays were more likely than implied motion displays to activate visual feature detectors, and consequently to produce effects arising from pointedness rather than conceptual knowledge. The hypothesis that similarity to real motion regulates cognitive effects receives further support from research into apparent motion. Short-range apparent motion has shorter temporal and spatial intervals than long-range apparent motion and thus is more similar to real motion. Accordingly, short-range apparent motion is also less susceptible to cognitive influences (Anstis, 1980; Braddick, 1980; Bruce & Green, 1990). Similarly, Shiffrar and Freyd (1990) created an apparent motion display of human body movements and found object-specific effects of solidity and joint structure only at longer Stimulus Onset Asynchronies (SOAs). In other words, object-specific effects did not manifest themselves at shorter SOAs, when the display was more similar to real motion. These hypotheses and findings highlight the need for further research into the relation between a display's similarity to real motion and cognitive effects in apparent motion and RM.

This study also has important implications for the types of constraints, object-specific or invariant, that operate on mental transformations. Object-specific constraints act only on the representations of a particular object (or basic-level category), whereas invariants act on all representations (Hubbard, 1995b, 1999; Shepard, 1984, 1994). Our results demonstrate that, at least in some cases, object-specific constraints do act on mental transformations. Moreover, given that our stimuli represented human artefacts of recent date, it seems undeniable that object-specific constraints can arise from learning about the represented objects, as opposed to being innate as is sometimes claimed for invariants (e.g. Shepard, 1984). Finally, our conceptual manipulation from Experiment 2 further indicates that this learning has a conceptual component; that it is not simply an association between a visual stimulus and its typical motion. In sum, our findings indicate the action of learned, conceptual object-specific constraints on mental transformations.

In conclusion, it is clear that object-specific constraints have an impact on RM. The object-specific constraints we have identified are conceptual knowledge of an object's typical motion, and the stimulus' prototypicality, that is, the extent to which a stimulus' overall visual appearance makes it a good exemplar of its category. The relationship between such object-specific constraints and invariants remains unclear. Further study is needed to determine whether they develop differently, whether they affect RM in different ways, and whether they affect RM through different mechanisms. Nonetheless, we now have a core set of empirical findings showing that what we know about objects and motion can influence RM. These findings demonstrate that any theory of RM cannot be based solely on environmental invariants, but must incorporate mechanisms allowing for conceptual effects.

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7 Appendix: Descriptions of the Atypical Rocket and Drill Rig Stimuli in Support of their Labels

The instructions provided to the participants contained the following stimulus descriptions.

7.1 Atypical Rocket

You may be wondering what kind of rocket this is. The drawing is based on a description from a science-fiction story that takes place in the near future. This type of rocket is used by miners on the moon to deliver ore to an orbiting space station. The ore is placed in containers that are stacked on top of each other. These containers actually form the main body of the rocket. (The rocket shown here has two containers.) Four legs are connected to the main body, and so are two rocket engines. The rocket is launched from the lunar mining site and is collected by a space shuttle which then brings it to the space station. At the space station, the ore is unloaded, the rocket is dismantled and sent back to the moon base in pieces. From the moon base, dismantled rockets are brought to the mining sites in large cargo carriers along with other supplies. When needed, the miners re-assemble a rocket, load it up and send it off again.

7.2 Drill Rig

The rig pictured here is an offshore drilling rig. It's used to tap deposits of oil and natural gas that lie under the ocean floor. The central part of the rig is called the platform and houses the machinery required in the drilling operations. It also houses the crew and their supplies. This type of rig is called a "jack-up rig" because the platform can be raised or lowered on its four legs. The legs are raised while the rig is towed into place. Once the rig is anchored, the legs are lowered until they rest on the sea bed. The platform is then raised slightly (jacked-up) above the water level.

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