Brief article

Minds in motion in memory: Enhanced spatial memory driven by the perceived animacy of simple shapes

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ABSTRACT

Even simple geometric shapes are seen as animate and goal-directed when they move in certain ways. Previous research has revealed a great deal about the cues that elicit such percepts, but much less about the consequences for other aspects of perception and cognition. Here we explored whether simple shapes that are perceived as animate and goal-directed are prioritized in memory. We investigated this by asking whether subjects better remember the locations of displays that are seen as animate vs. inanimate, controlling for lower-level factors. We exploited the 'Wolfpack effect': moving darts (or discs with 'eyes') that stay oriented toward a particular target are seen to be actively pursuing that target, even when they actually move randomly. (In contrast, shapes that stay oriented perpendicular to a target are correctly perceived to be drifting randomly.) Subjects played a 'matching game' – clicking on pairs of panels to reveal animations with moving shapes. Across four experiments, the locations of Wolfpack animations (compared to control animations equated on lower-level visual factors) were better remembered, in terms of more efficient matching. Thus perceiving animacy influences subsequent visual memory, perhaps due to the adaptive significance of such stimuli.

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1. Introduction

For decades, research on perceived animacy has emphasized that the currency of perception consists not only of low-level features such as color and orientation, but also of seemingly higher-level properties such as intentionality and goal-directedness. Even simple geometric shapes look animate when they move in certain ways (Heider & Simmel, 1944; Michotte, 1950/1991), and such phenomena seem to reflect visual processing rather than higher-level judgments – since they are resistant to the influences of intentions and knowledge, yet arise in a reliable and highly stimulus-driven manner (for a review, see Scholl & Gao, 2013). Moreover, such percepts seem highly consistent across cultures (Barrett, Todd, Miller, & Blythe, 2005), arise early in development (e.g. Csibra, 2008; Gergely, Nádasy, Csibra, & Bíró, 1995; Southgate & Csibra, 2009), and seem to operate in a consistent manner across all individuals, excepting only those with particular neuropsychological impairments such as autism spectrum disorder (e.g. Klin, 2000; Rutherford, Pennington, &

Rogers, 2006) or amygdala damage (e.g. Heberlein & Adolphs, 2004).

Despite the enduring interest in this topic (see Scholl & Tremoulet, 2000), the perception of animacy has often been treated as a sort of epiphenomenon – a curiosity with little functional relationship to the rest of the mind. However, merely detecting living things will not by itself enhance our fitness: to have adaptive value, these percepts must have downstream consequences for cognition and behavior. Inspired by this possibility, the present research explored some ways in which perceiving animacy may automatically influence the encoding of information into spatial memory.

1.1. Cues to animacy

Psychologists have identified several dynamic cues that cause objects to be seen as animate and goal-directed. Perhaps the simplest such cue is self-propulsion: moving geometric shapes are perceived as more animate when they change heading of their own accord, and as less animate when those heading changes can be explained by appeal to external forces acting on the object (e.g. Dasser, Ulbaek, & Premack, 1989; Pratt, Radulescu, Guo, & Abrams, 2010; Schultz & Bülthoff, 2013). Self-propelled motion is an especially strong cue to animacy when it is contingent upon other objects' locations or movements (Bassili, 1976), as when

one object begins moving away when another comes near (Michotte, 1950/1991). And others have argued that the perception of animacy is triggered both by general factors such as apparent violations of Newtonian mechanics (e.g. Gelman, Durgin, & Kaufman, 1995; Tremoulet & Feldman, 2000), and by spatiotemporal patterns related to specific forms of intentionality such as chasing (e.g. Dittrich & Lea, 1994; Gao, Newman, & Scholl, 2009; Gao & Scholl, 2011; van Buren, Gao, & Scholl, in press).

1.2. The wolfpack display

Beyond its vivid phenomenology, the perception of animacy can also influence visuomotor performance in several ways. In the 'wolfpack effect', for example (Gao, McCarthy, & Scholl, 2010), subjects maneuver a disc around a display filled with darts that move randomly but nevertheless stay oriented either toward the subject's disc (in *Wolfpack* displays) or 90° away from it (in *Perpendicular* control displays). Despite the objective similarity of these stimuli, they look categorically different, with Perpendicular darts perceived as randomly drifting, and Wolfpack darts perceived (erroneously) as pursuing the subject's disc. Arguably the most powerful demonstration of the wolfpack effect, however, involved its influence on visuomotor performance in the so-called *Don't Get Caught* task (Gao et al., 2010, Experiment 4). When subjects tried to avoid touching the randomly moving darts (and also another disc that objectively pursued the subject's disc) their evasion was dramatically less successful in the context of Wolfpack displays. (Indeed, the wolfpack stimulus is so salient that it changes behavior even when task-irrelevant: when subjects forage for 'food dots' while ignoring moving background darts, they forage less efficiently in the presence of the wolfpack; van Buren, Uddenberg, & Scholl, 2016.) These results highlight the power of such animacy cues, since subjects had every incentive to treat both display types as equivalent, and not to let the (subtly menacing) Wolfpack display impair their performance.

1.3. The current project: animacy and memory

The present research explores whether simple shapes that are perceived as animate and goal-directed are prioritized in memory.[1] We were inspired by recent research on 'adaptive memory' (for a review, see Nairne, 2014). This work has shown, for example, that after studying lists containing animate and inanimate words, subjects are more successful at recalling animate items than inanimate ones – even when controlling for factors such as imageability (Nairne, VanArsdall, Pandeirada, Cogdill, & LeBreton, 2013). We wondered whether an analogous pattern would hold far beyond the domain of word lists, for dynamic visual stimuli that are perceived as animate.[2] We report four experiments exploring whether the perception of 'minds from motion' influences spatial memory, using animations with both 'darts' and discs with 'eyes' (see Fig. 1).

2. Experiment 1: A 'matching game' (with darts)

We drew inspiration from children's 'matching games' in which players turn over panels two at a time to find matching pairs

(Wilson, Darling, & Sykes, 2011). (We will speak here of the *spatial* memory demands of this task, which likely taps a combination of working and long-term memory.) In our matching game, subjects click on panels to reveal animations with moving shapes (Fig. 1). After two animations are revealed, both disappear again, unless they match. Critically, the animations can be perceived as animate (via the Wolfpack display) or inanimate (via one of several control displays). (Sample trials 'playing back' a single subject's cursor movements are available for each experiment at http://perception.yale.edu/AnimacyMemory/ .) To perform efficiently, players must remember what they have seen, and where they have seen it, in order to find matching pairs as quickly as possible. Would this be easier for animate than for inanimate pairs?

2.1. Method

2.1.1. Subjects

Twenty-four subjects (with normal or corrected-to-normal acuity) participated in 60 min sessions for payment or course credit. (This sample size was based on a power analysis run on pilot data and was identical for all experiments. Details of this analysis can be found in the online supplementary data file.)

2.1.2. Apparatus

Stimuli were presented using custom software written in Python with the PsychoPy libraries (Peirce, 2007). Subjects sat in a dimly lit room without restraint approximately 60 cm away from the display, which subtended approximately 43.19° × 27.79°.

2.1.3. Stimuli

Stimuli were presented in a 43.02° × 26.14° region at the center of the screen. The display featured eight rectangular blue panels (each 10.58° × 12.88°), arranged in two rows of four (Fig. 1a). Panels were surrounded by thin (0.054°) black borders and separated by white lines of equal thickness. A (0.054°) white border separated the functional part of the display from the black periphery.

Each animation featured six white shapes moving on a black background within one of the panels. These consisted of a white disc (0.28°) and five white darts whose 'nose' and right and left 'wings' were located on the perimeter of an invisible (0.86°) circle, with a 120° angle between the nose and each wing. The disc initially appeared at a random location within the panel and the darts appeared in random locations within a (7.54° × 9.70°) rectangular region at its center, each at least 2.43° away from the disc. The disc moved at 4.05°/s, the darts moved at 3.24°/s, and each shape randomly changed direction within a 90° window (centered on its current heading) roughly every 367 ms. Whenever any darts were within 1.35° of the disc, it moved directly away from the nearest dart. Whenever any shape reached its respective border, it 'bounced' to remain within bounds. Darts in a given panel pointed either toward the disc (i.e. the Wolfpack stimulus), or to its right by 45°, 90°, or 135°.

2.1.4. Procedure

Subjects were told they would be matching panels on the basis of the darts' relative orientations to the disc. They used the mouse to move a white, cross-shaped cursor (0.27° × 0.27°) around the display and click on panels. On each trial, the panels hid two animations of each of the four types, with these assignments constant within trials but random across trials. The subject's first click caused the respective blank panel to be replaced by an animation. If no other click was made within 3 s, the animation disappeared and the blank panel reappeared. If a second panel was clicked within 3 s, however, there were two possible outcomes. If the animations matched, empty (and subsequently 'unclickable') black

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[1] Past studies have asked subjects to subjectively describe such displays from memory (Bloom & Veres, 1999), or have explored memory for other types of social visual stimuli such as faces (Balas & Pacella, 2015), or point-light figures, in which grouping of objects' internal features gives rise to the perception of a human form (Gao, Bentin, & Shen, 2015). Here, in contrast, we explore the influence of perceived animacy from simple geometric shapes on objective memory performance.

[2] Similar effects have been reported for pictures of animate vs. inanimate objects (Bonin, Gelin, & Bugaiska, 2014), but these images were presented alongside verbal labels, and subjects were instructed to explicitly categorize the stimuli as animate or inanimate.
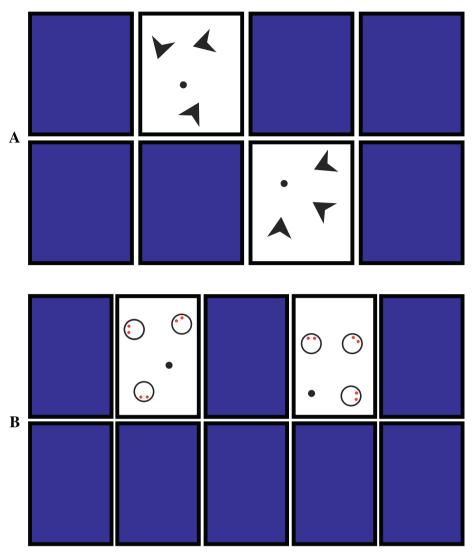
Fig. 1. (A) A depiction of the displays with 'darts' used in Experiment 1. The subject has revealed two non-matching panels (one containing darts offset by 45° and one containing darts in the 0° Wolfpack configuration). (B) An example of the displays used in Experiment 3 (featuring objects with 'eyes'). Here the subject has revealed two non-matching panels, one in which the objects are offset by 135° and one in which the objects face directly away from the disc. For clarity, the number of wolves per panel has been reduced from five (as used in the experiments) to three. Actual displays featured white shapes moving against a black background.

panels appeared in both locations, indicating that the matching pair had been eliminated. If the animations did not match, both remained visible for 3 s after the second panel was clicked (during which further clicks had no effect) before being replaced by blank panels. Subjects completed each trial as quickly as possible by eliminating three of the four pairs (with the final pair automatically eliminated and excluded from the analyses), after which the next trial began after a 400 ms blank delay. Subjects completed four practice trials (the results from which were not recorded) and forty experimental trials and received breaks after every tenth experimental trial.

2.2. Results and discussion

For each trial we computed four 'search inefficiency tallies' (SITs), which summed up instances of 'forgetfulness' for each of the four animation types. A SIT was incremented whenever (a) a first click was made to a previously seen panel without a second click then immediately making a match; (b) a lone visible animation 'timed out' when its match had been previously seen; (c) a subject's second click failed to select a match (if previously seen)

or a new panel (if not). This struck us as the simplest and most direct way of quantifying memory, by simply summing all instances of memory failure.

The resulting SITs are depicted in Fig. 2. Inspection of this figure suggests that the SIT for Wolfpack (0°) panels was lowest. This impression was verified by the following analyses. A one-way repeated measures ANOVA on SITs revealed a significant effect of animation type, $F(3,69) = 18.13$, $p < 0.001$, $\eta p^2 = 0.44$. As detailed in Table 1, three planned comparisons then confirmed that the Wolfpack SIT was lower than each of the others – with all of these comparisons being exceptionally robust (all $ts > 4.27$, all $ps < 0.001$, all $ds > 0.87$).[3] Subjects thus matched up Wolfpack animations more

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[3] Other differences existed as well, though they were not central to our questions and seemed less straightforward to interpret. For example, the SIT for 90° panels was numerically greatest here (as it was for all subsequent experiments), suggesting unsurprisingly that other factors beyond perceived animacy (such as canonical orientations) also influence memorability. Critically, however, factors of this sort cannot explain the effect of perceived animacy, given the advantage of perceived animacy over and above the addition of a 180° control condition in Experiments 2, 3, and 4.
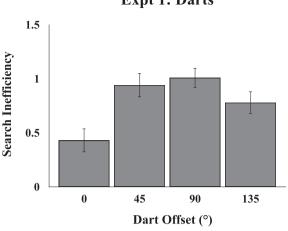
Expt 1: Darts

Fig. 2. Search Inefficiency Tallies for the different conditions in Experiment 1. Error bars in this and all subsequent graphs are 95% confidence intervals, subtracting out the shared variance.

efficiently, suggesting that perceived animacy facilitates the encoding of spatial information into memory.

3. Experiment 2: 180° control

Could the memory advantage for Wolfpack animations be due not to their perceived animacy, but simply to the convergence of the darts' symmetry axes? To find out, we added a control condition in which the darts pointed *away* from the disc – which controls for 'symmetry axis convergence' while eliminating the perception of animacy.

3.1. Method

This experiment was identical to Experiment 1 except as noted here. 24 new subjects participated. The display contained ten $8.44° \times 12.88°$ panels arranged in two rows of five. The darts were initialized within the $6.47° \times 9.70°$ region at the panel's center. Two new panels were added in which the darts pointed 180° (i.e. directly away) from the disc. Subjects completed each trial by eliminating four of the five pairs.

3.2. Results and discussion

The resulting SITs are depicted in Fig. 3. Inspection of this figure suggests that SITs for both Wolfpack (0°) and 180° panels were
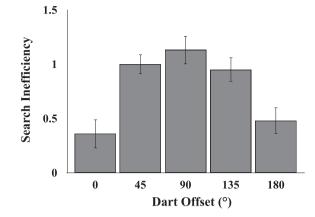
Expt 2: Darts 180° Control

Fig. 3. Search Inefficiency Tallies for the different conditions in Experiment 2.

lower than the others, but that the Wolfpack SIT was still lower than the 180° SIT. These impressions were verified by the following analyses. A one-way repeated measures ANOVA on SITs revealed a significant effect of animation type, $F(4,92) = 25.74$, $p < 0.001$, $\eta p^2 = 0.53$. As detailed in Table 1, four planned comparisons confirmed that the Wolfpack SIT was lower than all of the others, including the 180° SIT – with all of these comparisons being exceptionally robust (all $ts > 3.27$, all $ps < 0.004$, all $ds > 0.66$). These results suggest that converging symmetry axes may indeed influence subsequent memory, but they also confirm that the Wolfpack's advantage cannot be reduced to this factor.

4. Experiment 3: Matching with 'eyes'

Does the memory advantage for Wolfpack animations generalize beyond the specific 'pointy' dart stimuli used in the previous experiments? To find out, we replicated Experiment 2 using a very different oriented stimulus – discs with 'eyes' painted on one side (Fig. 1b). These stimuli are also robustly perceived in animate and intentional terms when they face a target in a Wolfpack configuration (e.g. Gao et al., 2010, Experiment 3b).

4.1. Method

This experiment was identical to Experiment 2 except as noted here. Twenty-four new subjects participated. Instead of darts, animations featured white discs (0.92°), with two red 'eye' dots on one

Table 1
Statistical comparisons between 0° panels and other panels for all experiments. Degrees of freedom for all one-sample *t*-tests shown is 23.

Comparison with 0°					
	Statistic	Expt 1	Expt 2	Expt 3	Expt 4
45°	*p*	<0.01	<0.01	<0.01	<0.01
	t	5.06	6.32	3.90	3.19
	Cohen's *d*	1.03	1.29	0.80	0.65
90°	*p*	<0.01	<0.01	<0.01	<0.01
	t	6.69	6.33	4.09	3.57
	Cohen's *d*	1.37	1.29	0.83	0.73
135°	*p*	<0.01	<0.01	<0.01	<0.01
	t	4.27	4.85	4.78	4.56
	Cohen's *d*	0.87	0.99	0.98	0.93
180°	*p*		<0.01	<0.01	0.04
	t		3.27	3.88	2.16
	Cohen's *d*		0.67	0.79	0.44

Expt 3: Objects with 'Eyes'

Fig. 4. Search Inefficiency Tallies for the different conditions in Experiment 3.
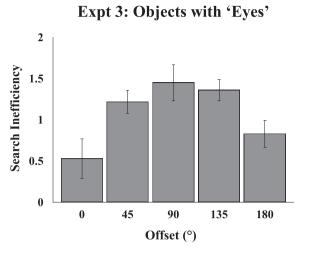
Expt 4: A Lone Wolf

Fig. 5. Search Inefficiency Tallies for the different conditions in Experiment 4.

side (0.18°, interdot distance = 0.27°, distance from each dot to the disc-center = 0.32°).

4.2. Results and discussion

The resulting SITs are depicted in Fig. 4. Inspection of this figure suggests that these results mirrored those of Experiment 2. These impressions were verified by a one-way repeated measures ANOVA ($F(4,92) = 13.57$, $p < 0.001$, $\eta p^2 = 0.37$). And as detailed in Table 1, four planned comparisons confirmed that the Wolfpack SIT was lower than all of the others – with all of these comparisons being exceptionally robust (all $ts > 3.87$, all $ps < 0.001$, all $ds > 0.79$). These results indicate that the memory advantage observed for objects facing a target is not specific to darts, or even to objects whose front is defined by a point.

5. Experiment 4: A lone wolf

The previous experiments each indicated an advantage for Wolfpack animations in subsequent memory. But how many wolves are necessary to drive this effect? To find out, we tested the most extreme case – a lone wolf, again depicted as a disc with 'eyes'.

5.1. Method

This experiment was identical to Experiment 3 except as noted here. Twenty-four new subjects participated. Animations contained a single oriented disc with 'eyes'.

5.2. Results and discussion

The resulting SITs are depicted in Fig. 5. Inspection of this figure suggests that these results mirrored those of Experiments 2 and 3. These impressions were verified by a one-way repeated measures ANOVA ($F(4,92) = 11.64$, $p < 0.001$, $\eta p^2 = 0.34$). And as detailed in Table 1, four planned comparisons confirmed that the Wolfpack SIT was lower than all of the others (all $ts > 2.16$, all $ps < 0.042$, all $ds > 0.44$). These results reveal that the influence of perceived animacy on memory does not depend specifically on the Wolfpack stimulus (or on the 'convergence of fronts' it employs).

6. General discussion

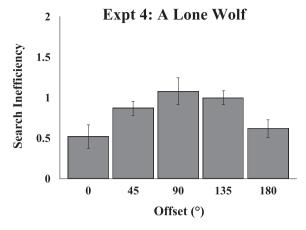Across four experiments, we consistently found a spatial memory advantage (as assessed in a simple 'matching game') for stimuli that are perceived in animate and intentional terms, via the Wolf-pack effect (Gao et al., 2010; van Buren et al., 2016). These effects occurred with both 'darts' (in Experiments 1 and 2) and 'eyes' (in Experiments 3 and 4), and they occurred in displays with a multiple-item Wolfpack configuration (in Experiments 1–3) and a 'lone wolf' (in Experiment 4). These effects are striking, given that the displays perceived as animate vs. inanimate are tightly controlled in terms of lower-level visual features (including motion energy, degree of correlated motion, and symmetry axis convergence). And it is also worth emphasizing that the 'animacy advantage' was always exceptionally robust, insofar as the Wolfpack panels were prioritized in memory over *all* other types of panels.

Past discussions of the perception of animacy have often implicitly treated it as an epiphenomenon, unrelated to more basic mental processes. The present results, in contrast, show how perceiving animacy can really *matter* for downstream processing, focusing here on spatial memory.

6.1. Animacy, attention, and adaptation

The present work was inspired in part by research demonstrating that animacy is privileged in visual attention. In change detection tasks, for example, subjects attend more to pictures of people and animals than to pictures of plants and vehicles (New, Cosmides, & Tooby, 2007; New et al., 2010; but see Hagen & Laeng, 2016). And similarly, with spatiotemporal cues to animacy, subjects are faster to respond to targets on objects whose heading changes appear to be due to internal forces, rather than inanimate collisions (Pratt et al., 2010). (These results confounded animacy with predictability, but related effects have been observed when such factors are controlled. For example, subjects are faster to detect probes which appear on an object that chases another object, but only when its quarry is visible; Gao, New, & Scholl, submitted for publication). These findings are consistent with the present results, given that attention and memory are often thought to be deeply intertwined (e.g. Chun, Golomb, & Turk-Browne, 2011).

The present work was also inspired by the view of 'adaptive memory', which suggests that natural selection shaped memory to prioritize information that mattered most to our ancestors' survival and reproduction (for a review, see Nairne, 2014). The present results may reflect this influence, given the importance of animacy and its detection: forgetting the locations of one's predators, prey, competitors, kin, or potential mates could dramatically and directly influence fitness, while forgetting the locations of puddles, branches, or other inanimate objects might at worst get one lost. (Indeed, in the case of moving objects, there might even be a *disin-*

centive to remember the locations of inanimate entities, since moving things such as clouds and waves are not useful as navigational landmarks.) The present results are consistent with the notion that, due to its adaptive relevance, the perception of animacy may be integrated into the mind in ways that are deeper and more specific than have been previously imagined.

Author note

Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2017.02.006.

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