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# Reasoning about 'irrational' actions: When intentional movements cannot be explained, the movements themselves are seen as the goal

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ABSTRACT

Infants and adults are thought to infer the goals of observed actions by calculating the actions' efficiency as a means to particular external effects, like reaching an object or location. However, many intentional actions lack an external effect or external goal (e.g. dance). We show that for these actions, adults infer that the agents' goal is to produce the movements themselves: Movements are seen as the intended outcome, not just a means to an end. We test what drives observers to infer such movement-based goals, hypothesizing that observers infer movement-based goals to explain actions that are clearly intentional, but are not an efficient means to any plausible external goal. In three experiments, we separately manipulate intentionality and efficiency, equating for movement trajectory, perceptual features, and external effects. We find that participants only infer movement-based goals when the actions are intentional and are not an efficient means to external goals. Thus, participants appear to infer that movements are the goal in order to explain otherwise mysterious intentional actions. These findings expand models of goal inference to account for intentional yet 'irrational' actions, and suggest a novel explanation for overimitation as emulation of movement-based goals.



## 1. Introduction

Typical humans understand other people's actions in terms of underlying mental states, such as beliefs, desires, intentions and goals, and not simply in terms of the raw movements perceived (Dennett, 1987; Saxe, Carey, & Kanwisher, 2004). Reasoning about intentions and goals develops early in life (Carpenter, Akhtar, & Tomasello, 1998; Carpenter, Call, & Tomasello, 2005; Gergely, Nádasdy, Csibra, & Bíró, 1995; Woodward, 1998), and plays a central role in parsing action sequences (Baldwin & Baird, 2001; Zacks, Tversky, & Iyer, 2001) and predicting others' future behavior (Woodward, 1998; Buresh & Woodward, 2007).

To infer the intentions and goals of another agent, adults and infants appear to consider whether the movements observed are consistent with particular hypothesized goals (Baker, Saxe, & Tenenbaum, 2009; Gergely et al., 1995). Goals are hierarchical, such that we engage in lower-level goals (e.g. reach for the coffee maker) in order to achieve a higher-level goal (e.g. obtain coffee), which itself contributes to an even higher-level goal (e.g. happiness). Because we assume that agents act rationally, for lower-level goals in this hierarchy (e.g. reach for the coffee maker) movements are seen as consistent with a hypothesized goal when they are an efficient means to that goal (Dennett, 1987; Gergely, Bekkering, & Király, 2002; Gergely et al., 1995). Conversely, if the movements are not an efficient means to a possible goal, this inefficiency provides evidence against that goal (Baker et al., 2009). This rationality assumption underlies current accounts of low-level-goal based reasoning about a variety of actions,

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ranging from reaches and interactions with objects (Gergely et al., 2002; Southgate, Johnson, & Csibra, 2008) to directed locomotion (Baker et al., 2009; Gergely et al., 1995).

However, humans worldwide also regularly observe dance and ritual actions (Nettl, 1983; Royce, 2002), which are fundamentally different from actions explored in past literature. For example, imagine an agent sliding right and then left; jumping once up and down; sliding left, then right; and then moving through the entire sequence again. Unlike reaching for an object or going to a certain spot, these dance-like movements are not an efficient means to any object or location. As such, these movements appear to lack low-level goals, such as reaching an object or location.

### 1.1. Reasoning about dance-like actions

How do we reason about these ostensibly goal-less movements? One possibility is that we conclude that the agent's intent was simply to produce the movements (e.g., to jump and then slide, or to move in a pattern). In this case, the movements would not just be the means to an end; certain aspects of the movements would be an end in themselves. In effect, performing the movements would be the goal.

An alternative possibility is that observers may be unable to treat aspects of movement as a goal, and thus may be unable to identify a specific intention or goal for these actions. Indeed, this is what much current literature assumes: Because many studies of goal understanding use movement as a foil for goal representation, these methods tend to equate encoding of the particular movements with failing to represent goals at all. For example, Woodward (1998), Gergely, Nádasdy, Csibra, and Bíró (1995) and Meltzoff (1995) constructed each of their seminal experiments such that expecting or producing the movement previously observed was inconsistent with goal-based reasoning. In more recent literature, authors have explicitly excluded the possibility that one's goal may be to produce specific movements, by defining the concept of goal as requiring an external effect on the environment, or claiming that actions are only perceived as goal-directed when they efficiently bring about a change of state in the world (e.g. Csibra, 2003; Király, Jovanovic, Prinz, Aschersleben, & Gergely, 2003; Southgate et al., 2008).

Here we test this narrow construal of goals by exploring the novel domain of dance-like actions. We ask whether observers can infer that an agents' goal is to produce the movements themselves. We suggest there are two types of goals: *External goals* and *movement-based goals.* For external goals, the intended outcome is a relation to or interaction with the external environment (e.g., reaching a location, getting an object). In this case, the movements themselves are interchangeable and auxiliary, because they are simply the means to an external end. In the current paper, we hypothesize the existence of *movement-based goals*, for which implementing an aspect of the movement is the intended outcome (e.g., to jump, to move around and not stay still, to move in a specific pattern).

We expect movement-based goals to be cognitively akin to low-level external goals, such as reaching for an object or getting to a location (not higher-level external goals like finding a romantic partner), and to be represented at this level of analysis. This is the level at which goals can be inferred through physical-causal analyses and understanding of mechanical constraints (along with an expectation of efficiency), and the level typically studied in literature on action understanding and goal inference (e.g. Baker et al., 2009; Gergely et al., 1995; Woodward, 1998).

### 1.2. Why infer that movements are the goal?

Goals serve as explanations for other people's actions: When we observe another person moving in a way that seems intentional, we seek to explain those actions in terms of the goals that motivated the movements (Gergely & Csibra, 2003; Lombrozo, 2010). However, some movements lack a clear explanation, because they are not an efficient means of achieving any plausible external goal. In this case, observers may use the idea that the movements themselves are the goal as a means of explaining why people are doing what they are doing. In other words, when external goals fail to explain intentional movements, people may explain the movements' existence by concluding that the person's goal must have been simply to produce the movements.

Goal inference has been modeled as a type of Bayesian inverse planning, in which the observer considers multiple possible goals, and weighs the probability of each based on their prior probability as well as the efficiency of the movements as a means to each goal (Baker et al., 2009). This Bayesian framework can give us leverage into when and why observers might conclude that movement is the goal, using the principle of the Bayesian Occam's razor (MacKay, 1992, 2003). Imagine comparing the probability of two hypotheses, where one hypothesis can predict a wide range of data, and another hypothesis only predicts a more narrow range of data. If we observe data that is consistent with both hypotheses, this actually gives stronger evidence for the second hypothesis, because it more specifically predicted those data. In other words, it would be a suspicious coincidence if the first hypothesis were true, when out of the wide range of possible data, you observed the type that is also consistent with the second hypothesis (Tenenbaum & Griffiths, 2001; Xu & Tenenbaum, 2007). For instance, if you are told that a computer either outputs only even numbers or only powers of two, and the computer then outputs 16 and 64, you are more likely to think that it is outputting powers of two than even numbers, even though the output is consistent with both hypotheses (Tenenbaum & Griffiths, 2001).

Like the first hypothesis in this example, the broad class of movement-based goals does not make specific predictions as to what movements are expected. Indeed, all movements are consistent with some movement-based goal, as every possible movement path and pattern is a potential goal. In addition, although individual movement-based goals may make highly specific predictions (e.g. the goal 'slide right, slide left, jump and repeat'), each of

these individual goals is unlikely because of the huge number of possible movement-based goals: The total prior probability of movement-based goals (as a class) must be divided among these individual goals, giving each one a low probability. Because of the lack of specific predictions of the broad class of movement-based goals, and vast number of possible individual movement-based goals, these goals should be seen as less likely than external goals when both are consistent with the observed movements. Thus, if observers infer movement-based goals through Bayesian inference, they should conclude that movements are the goal only when the movements are not an efficient means to achieve external goals (yet are clearly intentional), leaving them without any better explanation for the action.

The first aim of the current studies is to determine whether observers ever spontaneously and intuitively infer that an agents' goal is to produce movements. We then aim to determine what drives this goal attribution. We hypothesize that observers will make this inference to explain movements that are clearly intentional, yet are not an efficient means to other plausible goals, in line with use of Bayesian inference. In three experiments, we separately manipulate intentionality and inefficiency to test whether these factors drive observers to infer movement-based goals. We contrast this hypothesis with several non-inference-based alternative accounts, asking whether the path, pattern or amount of movement, low-level perceptual features, or failure to change the environment could cue movement-based goals.

## 2. Experiment 1

In a first experiment, we compare observers' understanding of the same movements when they are or are not an efficient means of achieving a plausible external goal, thus manipulating this factor while equating for movement trajectory. To supply a plausible external goal while maintaining identical movements, we manipulated the presence or absence of objects in the environment, adding colored balls and boxes such that the character appears to sort balls into boxes by color (see Fig. 1, and Videos 1 and 2). After verifying that participants perceived the actions as intentional, we used open-ended free-response questions ("What was the characters' intention?") to capture participants' spontaneous inferences about the character's intent, thus avoiding suggesting potential answers.

Observers typically expect that goals remain consistent throughout an action sequence (Baldwin, Baird, Saylor, & Clark, 2001; Gergely et al., 1995; Olofson & Baldwin, 2011; Woodward, 1998). Thus we used a violation-of-expectation type paradigm to further probe the goals participants inferred, and to verify free-response answers. In particular, we showed observers one of two possible continuations of the characters' actions, and asked whether this was what they expected the character to do, or not (see Fig. 1, and Videos 3–6). If observers have inferred that the characters' goal is to produce the specific movements, they should expect the character to continue the same movement pattern (e.g. left–right alternation), thus continuing to fulfill this goal. In contrast, if observers have inferred an external goal (e.g. sorting balls into boxes by color), they should expect the character to continue fulfilling this goal, even when this means violating the established pattern of movement.

We predict that observers will often conclude that the character's goal is to produce the movements when there is no plausible external goal to explain the actions. In contrast, when a plausible external goal is available participants should not draw this conclusion, even when observing identical movements.

### 2.1. Method

#### 2.1.1. Participants

128 adult residents of the United States (18+ years of age) took part in the experiment over the internet, via the Amazon Mechanical Turk website (MTurk, https://

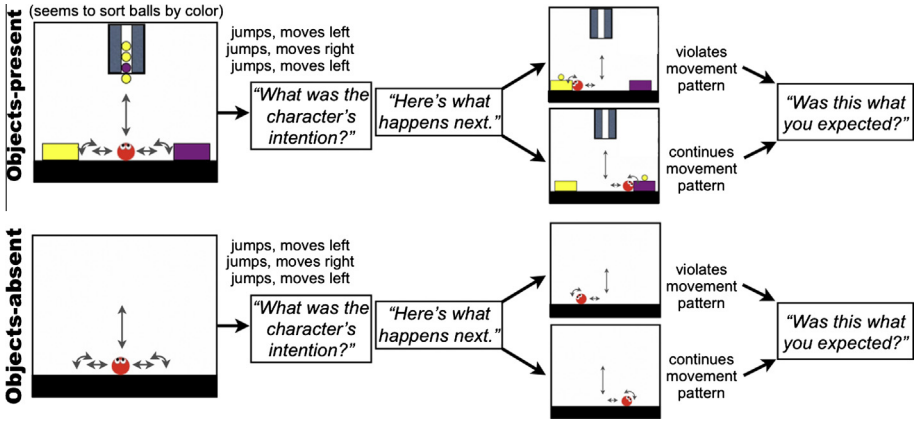


**Fig. 1.** Method and stimuli, Exp. 1. In both the objects-present and objects-absent conditions, the character jumped, moved left (and back to center), jumped, moved right, jumped, and moved left, after which participants were asked to describe his intention. In a subsequent second video, participants were shown the character's next actions, consisting of a jump and either a leftward or rightward movement, and asked whether this was what they had expected the character to do next. Rightward movement was consistent with continuing the movement pattern. Leftward motion violated the movement pattern; however, it was consistent with a plausible external goal in the objects-present condition (sorting the balls by color). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

www.mturk.com). To participate, individuals were required to have had at least 93% of their previous work judged as acceptable; this criterion was determined a-priori based on criteria used in the literature (Berinsky, Huber, & Lenz, 2012; Goodman, Cryder, & Cheema, 2012; Mason & Suri, 2011). All participants gave informed consent, and were paid $0.30 for approximately 3 min of their time. Repeat participation by the same individual was not allowed (each participant was identified by a unique and stable code by the MTurk system). Each participant took part in only one condition (objects-absent or objects-present). Half of the participants in each condition received the test video in which the character moved to the left (violating the movement pattern), while the other half received the test video in which the character moved to the right (continuing the movement pattern).

Of the 128 participants in the final sample, 102 took part in the objects-absent condition and 26 took part in the objects-present condition. A greater number of participants were run in the objects-absent condition because data were analyzed as a function of the goal inferred, and more goals were inferred in the objects-absent condition than the objects-present condition: These numbers resulted in approximately comparable numbers of participants in each of the key sub-groups across both conditions. 27 additional participants were run, but excluded from the final sample for leaving answers blank (16); technical problems viewing the videos (4); giving unrelated text answers showing that the videos had not been watched (1); or indicating misunderstanding of instructions (6).

#### 2.1.2. Stimuli

Animated stimuli were constructed using Apple iWork Keynote '09 and Apple Quicktime Pro software. Each of the two conditions (objects-present and objects-absent) consisted of one first video, and two possible second videos (see Fig. 1, and Videos 1–6). In the first video, the animated character performed a sequence of movements with an alternating left–right pattern: jump once, move *left,* rotate left 45°, rotate back 45°, move right to return to original location; jump once, move *right*, rotate right, rotate back, return to original location; jump once, move *left*, rotate left, rotate back, return to original location (left–right always specified from the viewers' perspective). In the second video, the character first performed these same movements, and then performed one additional sequence of movements (the word "NEW" appeared, to cue participants to note the additional sequence). The additional sequence was either a leftward sequence (jump, move left), or a rightward sequence (jump, move right).

In the objects-absent condition, the character performed the movements in an apparently empty space, while in the objects-present condition there were colored boxes and balls, including a yellow box to the left, a purple box to the right, and four balls in a container above the character colored yellow, purple, yellow, yellow (from bottom to top). As the character performed the movement sequence, he appeared to jump to retrieve each ball and place it into its color-matched box. At the end of the first video, one yellow ball remained unsorted. In the new sequence of the second video, the character either placed this ball in the yellow box on the left or in the purple box on the right. Thus stimuli were constructed such that continuing to fulfill the salient external goal (sorting balls by color) would require the character to violate the movement pattern in this new sequence.

In order to examine goal inferences for intentional actions, the character was designed to appear animate, and movements were designed to appear intentional. The character exhibited multiple known cues to animacy, including self-propelled motion (Tremoulet & Feldman, 2000), and eyes (Hamlin, Wynn, & Bloom, 2007; Johnson, Slaughter, & Carey, 1998). The character was referred to using a common human name (Tim) and appropriate pronoun ('he', not 'it'). The character's actions exhibited multiple cues to intentionality, including smooth movements with trajectory changes un-imposed by the environment (Gelman, Durgin, & Kaufman, 1995; Tremoulet & Feldman, 2000, 2006), and patterning and repetition of movements (see Section 5). A manipulation check allowed us to verify that participants perceived the actions as intentional.

#### 2.1.3. Procedure

Participants were asked to watch a video featuring a character named Tim. After watching this first video participants answered one free-response question, "What was Tim doing?", and one forced-choice question, "Were Tim's actions intentional, or accidental?" Participants then clicked a link to submit these answers, and move to a second page. Participants could not return to previous pages after moving forward to a new page, preventing revision of answers based on subsequent information.

The second page contained a single free-response question: "In the video, what was Tim's intention?". On the third page, participants read: "Next you will watch the same video again, but this time it will continue, to show Tim's next action as well. The word "NEW" will appear in the video to cue you at this point. Please judge whether the action shown is what you predicted that Tim would do next, or not." After viewing this second video, participants were asked, "Was this what you expected Tim to do next?", with three possible answers: "Yes, this is exactly what I expected"; "No, this is not quite what I expected"; and "No, this is not at all what I expected". Lastly, participants were asked two free-response questions: "Please describe what you expected Tim to do next," and "Why did you think Tim would do that next?".

#### 2.1.4. Data analysis

The question asking whether the actions were intentional or accidental was used as an initial methodological check, to ensure that stimuli were seen as intentional. Answers to the open-ended question regarding intention were coded to determine the type of goal the participant had inferred, if any. Answers to the violation-of-expectation question were coded as either 'yes, expected' or 'no, unexpected' (i.e. the two negative answers were treated equivalently). To analyze these data, we divided participants into sub-groups based on type of goal inferred, and examined differences in prediction as a function of condition and goal inferred. Answers to the final two free-response questions were used to verify that participants had understood

instructions in the violation-of-expectation task; participants who stated that they thought that the appearance of the word "NEW" implied that they should 'expect the unexpected' were excluded. The free-response question "What was Tim doing?" was included to detect and exclude participants who had not viewed the video or did not speak English, by excluding those who gave nonsensical answers to this clear-cut question. However, such answers were extremely rare, and were only provided by participants who also left other answers blank (and were thus excluded for that reason).

#### 2.1.5. Coding of free-response answers

To determine the type of goal the participant had inferred, if any, participants' answers to the free-response question "What was Tim's intention?" were coded into representative descriptive categories, based on the goal described. Similar coding of text answers to open-ended questions has been used in previous studies of this type (e.g. Gelman et al., 1995). Coders were blind to participants' subsequent answers, crucially including their violation-of-expectation answers. Responses were recoded by a second, independent coder for reliability; in rare cases of disagreement, the first coder's designations were used. The two coders agreed on 96.0% of participants' category designations (123/128 participants).

Answers were coded as indicating an external goal when the movements were described as the means to an external end, such that the goal was in or about the character's external environment (e.g. [Tim's intentions were] "sorting balls into boxes", "trying to jump over a fence", "to escape from something"; see Table 1 for representative examples). Answers were coded as indicating a movement-based goal when they included descriptors of the movement without reference to an external reason for the movement (e.g. [Tim's intentions were] "to jump, and then slide", "to move around", "to bounce in that pattern"; but not "to jump to look around"; see Table 1).

Answers were coded as ambiguous if the category of the answer given could not be clearly interpreted. Answers were coded as 'no goal' if no goal was inferred (e.g. "Tim didn't have an intention"), and as 'not sure' if the participant stated that they were unsure or did not know and did not supply a guess.

Lastly, additional categories were added to capture answers that were not unambiguously movement-based goals or external goals, and thus did not meet coding criteria for either category, but which we hypothesized might be higher-level aims that involve movement-based goals. These included (1) dancing, (2) exercising, (3) performing a ritual, (4) entertaining oneself/others or expressing one's happiness, (5) practicing or testing one's physical abilities. This hypothesis was driven by the observation that these goals can be fulfilled by producing specific movements that are often not an efficient means of achieving any external goal (e.g. dance actions). To explore this idea, we analyzed the responses of participants who inferred these goals, to see if they patterned with those of participants who inferred movement-based goals with respect to (a) the conditions under which these goals were inferred, and (b) their predictions of the character's next movements.

### 2.2. Results

The vast majority of participants' answers were easily and unambiguously coded into a single one of the categories

**Table 1**
Observers' answers to the question 'What was the character's (Tim's) intention?', Exp. 1. Representative examples of answers coded as external goals and movement-based goals, from participants in the objects-absent and objects-present conditions.

| | What was the character's intention? Representative answers | |
|---|---|---|
| | External goals | Movement-based goals |
| Objects-absent condition | I believe Tim's intention was to bounce up to get something or get onto something | Tim's intention was to jump into the air and move to the left and right |
| | I think that Tim's intention was to find an object | His intentions were to jump up and down, and move side to side |
| | He seems to be searching for something | Tim's intention was to perform a little series of bounces and slides: to entertain |
| | Tim's intention was to jump high enough to see something | He didn't seem to have one other than jumping and sliding |
| | Attempting to reach something | To jump and land and turn |
| | To grab or touch something high up | To jump and roll around |
| | Tim's intention was to get as high as possible | His intention was to jump |
| | Tim's intention seemed to be reaching something above him. Either that or he's trying to shake some water from hts ears | Tim's intention was to move around in whichever direction he decided |
| | To reach something up in the air | To move around and have some fun |
| | It looked as though Tim was trying to see something that was blocked by a large object or perhaps several other, larger people (none of which are visible to me) | To jump, then move from one side to the other and tilt his head, then move back to the middle and repeat on other side |
| | To try and catch something by jumping | His intention was to move in a predictable pattern |
| | Tim's intention was to catch the thing he was jumping for | Moving rhythmically. It was almost like he was dancing |
| Objects-present condition | To place balls in the correct boxes | None |
| | To put colored balls into matching colored bins | |
| | To sort the colored balls | |
| | To separate the balls by color | |

above (106/128). However, some participants considered more than one possible goal (15/128), or gave an answer that was ambiguous (7/128). If a participant named more than one alternative goal, both were coded, in order to accurately reflect the incidence of each goal inference. Participants who inferred both movement-based goals and external goals were not included in violation-of-expectation analyses, as there was no way to determine which of the two alternative goals the participant would use in subsequent reasoning.

*2.2.1. Intentionality check*

In response to the forced-choice question asking whether the characters' actions were intentional or accidental, 100% of participants answered that the actions were intentional, not accidental (102 out of 102 in the objects-absent condition and 26 out of 26 in the objects-present condition).

*2.2.2. Character's intention: Objects-present condition*

In response to the question "What was Tim's intention?" participants in the objects-present condition inferred an external goal, stating that the character's intention was sorting the balls into the boxes (26 out of 26; see Table 1 and Fig. 2). No participants inferred movement-based goals (0 out of 26).

*2.2.3. Character's intention: Objects-absent condition*

In response to the question "What was Tim's intention?", 50 of the 102 participants, or 49.0%, inferred a movement-based goal, answering that the character's intention was to produce the movements. This incidence is significantly higher than that in the objects-present condition (50 out of 102 versus 0 out of 26; $\chi^2 = 20.9$, $df = 1$, two-tailed $p < .0001$). Thirty-three of the 102 participants, or 32.4%, inferred an external goal, in which the movement was the means to an external end.

Also in contrast to the objects-present condition, several participants stated that the characters' intention was to dance (7/102 participants), to exercise (3/102), to perform a ritual (1/102), to entertain himself or another (9/102), or to practice or test his abilities (3/102). Only 2 of the 102 participants said that the character had no intention; an additional two participants answered that they did not know what the character's intention was (see Table 1 and Fig. 2).

In the analysis above, the number of inferred goals sums to a number greater than the number of participants; this is because 15 of the 102 participants inferred multiple alternative goals (see Supplemental data for complete distribution).

*2.2.4. Prediction data: Objects-present condition*

Participants in the objects-present condition reliably expected the character to produce movements consistent with sorting the balls by color, in violation of the movement pattern. 92.3% of participants' answers were consistent with the goal of sorting balls by color; only 7.7% of participants' answers were consistent with continuing the movement pattern, a rate significantly below chance (2 out of 26; two-tailed binomial test $p < .0001$; see Fig. 3). Specifically, only two of the 13 participants who saw the move-right test video said it was expected, while 13 of the 13 who saw the move-left video said it was expected.

*2.2.5. Prediction data: Objects-absent condition*

As participants in the objects-absent condition inferred multiple goals, we divided participants into sub-groups based on the type of goal inferred, and examined

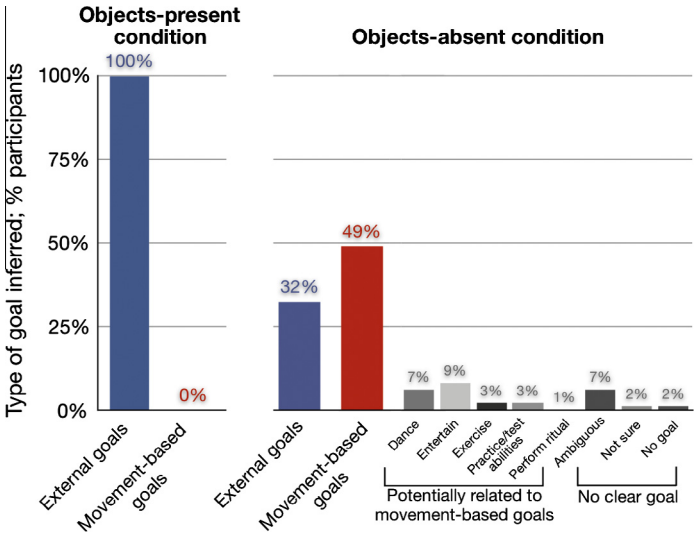


**Fig. 2.** Goals inferred in the objects-present condition (left) and objects-absent condition (right), Exp. 1. Despite the fact that observers all saw the exact same sequence of movements, observers in the objects-present condition always inferred external goals, whereas those in the objects-absent condition frequently inferred movement-based goals, as well as goals potentially related to the idea that movement is the goal, i.e. as higher-level goals that are achieved through movement-based goals (e.g. dancing). Because some participants inferred multiple alternative goals, percentages sum to greater than 100%.

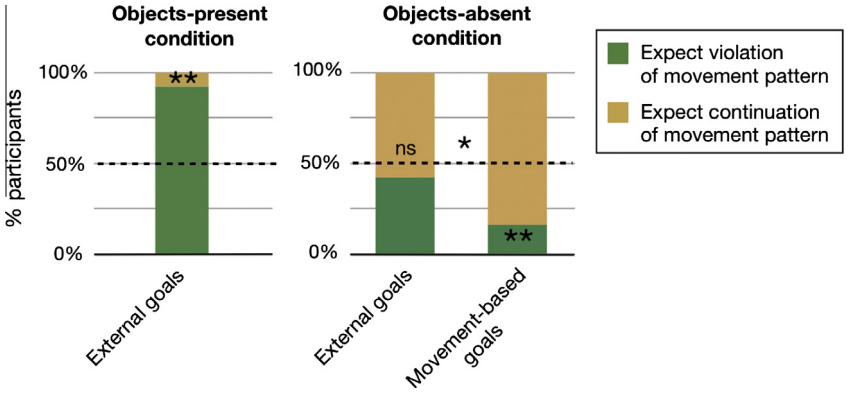


**Fig. 3.** Participants' predictions of the character's next action, as a function of the goal each participant inferred, Exp. 1. Participants' predictions of the character's next movements differed as a function of the type of goal they had inferred, even for participants who had seen the exact same stimuli: those who inferred movement-based goals expected the same movement pattern to continue, whereas those who inferred external goals did not make this prediction, both in the objects-present and objects-absent condition.

differences in prediction as a function of goal inferred. Participants who inferred both movement-based and external goals ($n = 7$) were not included in these analyses.

Participants who inferred movement-based goals consistently expected that the character would continue the same movement pattern: 83.7% of these participants' expectations were consistent with continuing the movement pattern, a rate significantly above chance (36 out of 43 participants, two-tailed binomial test $p < 0.0001$) and significantly different from that in the objects-present condition (36 out of 43 versus 2 out of 26; $\chi^2 = 37.9$, $df = 1$, two-tailed $p < .0001$). Specifically, 21 of the 24 participants who saw rightward movement at test said that this was what they had expected; only four out of the 19 participants who saw leftward movement at test said it was what they had expected.

In contrast, participants who saw exactly the same stimuli but inferred an external goal did not consistently expect that the character would continue in the same movement pattern. Overall, only 57.7% of participants' expectations were consistent with continuing the movement pattern. Specifically, 3 out of the 9 participants who saw rightward movement at test said that it was what they had expected; 5 of the 17 participants who saw leftward movement said that it was what they had expected. This rate of expecting continuation of the movement pattern is no different from chance (15 out of 26 participants, two-tailed binomial test $p = .56$), and is significantly lower than the rate for participants who saw the exact same stimuli, but said that the movements were the goal (36 out of 43 versus 15 out of 26; $\chi^2 = 5.69$, $df = 1$, two-tailed $p = .017$; see Fig. 3). Thus, participants' predictions of the character's next movements differed as a function of what goal they had inferred, even for participants who had seen the exact same stimuli.

In addition, we analyzed the predictions of participants who inferred no goal or gave answers that were judged ambiguous. Unlike participants who inferred movement-based goals, these participants did not consistently expect that the character would continue in the same movement pattern. Overall, only 45.5% of participants' expectations were consistent with continuing the movement pattern. This rate is no different from chance (5 out of 11 participants, two-tailed binomial test $p = 1.0$) and is significantly lower than the rate for participants who inferred movement-based goals (5 out of 11 versus 36 out of 43; $\chi^2 = 7.02$, $df = 1$, two-tailed $p < .01$).

Lastly, we analyzed the predictions of participants who inferred goals that were not unambiguously movement-based or external, but that we hypothesized to be related to movement-based goals. These goal inferences occurred only in the objects-absent condition, and included dancing, exercising, performing a ritual, entertaining oneself or others, and practicing/testing abilities. In line with our expectations, 75% of participants who inferred these goals expected the character to continue the movement pattern, a rate significantly higher than chance (15 out of 20 participants, two-tailed binomial test $p = .041$).

### 2.3. Discussion

The current dataset provides strong evidence that movements can be seen as the goal, not just a means to an end: Nearly half of the participants in the objects-absent condition spontaneously inferred that the character's intention was solely to produce the movements. Participants explicitly stated these inferences, and also predicted the character's subsequent movements in a manner consistent with their stated goal attributions: Those who inferred that movements were the goal expected the character to continue the same movement pattern, while participants who inferred an external goal or no clear goal did not. These expectations were not solely driven by perceptual features of the stimuli: Even participants who had viewed exactly the same stimuli formed different expectations about the characters' actions based on the type of goal they inferred.

Some participants spontaneously inferred that the character had other goals, such as dancing, exercising, or entertaining himself. The responses of participants who inferred these goals patterned with the responses of participants who inferred movement-based goals in two ways: These

goals were only inferred in the objects-absent condition, and participants who inferred these goals expected the character to continue the movement pattern (unlike participants who saw the same stimuli but inferred external goals, or did not infer any clear goal). This finding suggests that there may be a relationship between the idea of movement as the goal, and higher-level action concepts such as dance and exercise: For instance, these may be more abstract goals that are achieved through movement-based goals.

#### 2.3.1. An alternative: Invalid goal inference measures

Our argument that participants represented movements as the character's goal depends primarily on their answer to the question "What was the character's intention?" Is it possible that we have over-interpreted participants' responses? Perhaps participants describe the character's movements not because they have inferred movement-based goals, but simply because they do not know the answer. If participants do not know the answer but feel pressure to provide a response, they might describe the character's movements simply because it is the only information they have encoded. To test this possibility, in Experiment 2 we ask participants a question to which they do not know the answer, namely: "What was the character keeping secret?" If movement-based answers are caused by participants' uncertainty, lack of an answer, or unwillingness to oppose the pragmatic demands of a question, participants should similarly answer this question by describing the characters' movements.

In our second experiment, we also test the validity of our goal inference measure by conducting an 'unintentional movement' control condition. In this condition, participants see the same movements as in Experiment 1, but the movements appear unintentional (the character appears to be sleeping, while being moved by an external object). If our goal inference measures are valid, participants who view unintentional movements should not say that the movements are the characters' intention, while those who see the same movements performed intentionally should infer movement-based goals.

In addition, by manipulating whether actions were intentional or unintentional, we aimed to probe the role of intentionality in movement-based goal inferences. We hypothesized that movements must appear intentional for participants to infer that the movements are the goal.

## 3. Experiment 2

In a second experiment, we manipulated whether the characters' actions appeared intentional or unintentional. This allowed us to (1) test the hypothesis that movements must be intentional for observers to infer movement-based goals, and (2) verify the validity of our goal inference measures.

In the intentional movement condition, we replicated the objects-absent condition of Experiment 1, in which the character performed the movements in an apparently empty space. The movements appeared self-propelled, as there was nothing visibly contacting or pushing the character. In the unintentional movement condition, the character moved in exactly the same trajectory, but the movements appeared unintentional. To make this plausible, we depicted the character as sleeping, while being pushed by a mechanical object.

To verify the validity of our goal inference measure, we also asked participants a question to which they did not know the answer: "What was the character keeping secret?" If movement-based answers are caused by participants' uncertainty, lack of an answer, or unwillingness to oppose the pragmatic demands of a question, then participants should answer this question by describing the characters' movements. If our goal inference measures are valid, such that participants truly infer movement-based goals, then participants should not answer this new question by describing the characters' movements.

### 3.1. Methods

#### 3.1.1. Participants

Sixty-two adult residents of the United States (18+ years of age) took part in the experiment over the internet, via the Amazon Mechanical Turk website using the same qualification procedures as in Experiment 1, with the additional requirement that they had not previously participated in Experiment 1. Thirty and thirty-two participants took part in the two conditions; two extra participants were run in the intentional condition to equate the number of participants who passed the intentionality manipulation check, and thus were included in analyses of goal inference. Two participants were additionally run, but excluded from the final sample due to leaving answers blank. Each participant took part in only one condition.

#### 3.1.2. Stimuli

As in Experiment 1, each condition consisted of one first video, and two possible second videos (see Fig. 4). Participants in the 'intentional movement' condition viewed the same videos as in the objects-absent condition of Experiment 1 (Videos 1, 3 and 4). Participants in the 'unintentional movement' condition saw the character move in the same path, but do so unintentionally (Videos 7–9). To make the unintentional movements plausible, we depicted the character as being pushed and lifted by a mechanical object while asleep. (The character was depicted as sleeping to avoid the implication that the character was intentionally choosing to be pushed by choosing to remain in place.)

#### 3.1.3. Procedure

Questions and text were identical to that of Experiment 1, with two exceptions: the addition of one control question ("What was Tim keeping secret?"), and several minor wording changes to ensure that wordings were equally appropriate when referring to intentional and unintentional actions. Any effect of wording was tested and controlled for by replicating the objects-absent condition of Experiment 1 with the new wordings.

Specifically, the forced-choice question about intentionality was: "Did Tim intend to move in this way, or not?" The free response questions were as in Experiment 1:

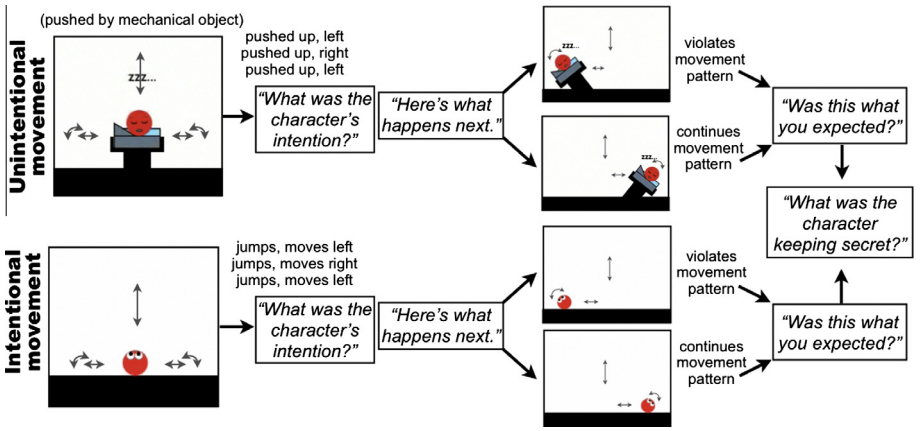


**Fig. 4.** Method and stimuli, Exp. 2. In both the intentional and unintentional movement conditions, the character moved up, left (and back to center), up, right, up, and left, after which participants were asked to describe his intention. In a subsequent second video, participants were shown the character's next actions, consisting of a movement up and either a leftward or rightward movement, and asked whether this was what they had expected to happen next. Rightward movement was consistent with continuing the movement pattern. Leftward motion violated the movement pattern. Lastly participants were asked an additional control question, "What was the character keeping secret?", to test if movement-based answers were due to uncertainty.

"What was Tim doing?" and "In the video, what was Tim's intention?". The instructions and questions for the violation-of-expectation task were: "Next you will watch the same video again, but this time it will continue, to show Tim's next movement as well. The word "NEW" will appear in the video to cue you at this point. Please judge whether the movement shown is what you predicted would happen next, or not. Was this what you expected to happen next?; Please describe what you expected to happen next; Why did you think that would happen next?" On an additional final page, participants were asked a last free response question: "In the video, what was Tim keeping secret?".

#### 3.1.4. Data analysis

As in Experiment 1, the question asking whether the movements were intentional or not was used as an initial methodological check. Participants were not included in further analyses if they failed the manipulation check (by answering that actions designed to appear intentional were not intentional, or vice versa). This criteria lead to the exclusion of only two participants, and this exclusion did not change findings.

#### 3.1.5. Coding of free-response answers

As in Experiment 1, the type of goal inferred by the participant was determined by coding participants' answers to the question "What was Tim's intention?" into representative descriptive categories. Coding was done in the same way as in the first experiment, with the addition of two new categories (the goals of 'sleeping' and 'waking up'). Responses were recoded by a second, independent coder for reliability; in rare cases of disagreement the first coders' designations were used. The two coders agreed on 93.5% of participants' category designations (58 of 62 participants).

Free-response answers to the question "What was Tim keeping secret?" were coded into three categories: "don't know", "nothing", and "other answers". Responses were recoded by a second, independent coder for reliability; the two coders agreed on 100% of participants' category designations (62 of 62 participants).

### 3.2. Results

#### 3.2.1. Intentionality check

In response to the forced-choice question asking whether the characters' movements were intentional or not, participants in the intentional movement condition answered that the movements were intentional (30 out of 32), while participants in the unintentional movement condition answered that the movements were not intentional (30 out of 30).

#### 3.2.2. Character's intention: Unintentional movement condition

In response to the question "What was Tim's intention?", the majority of participants stated that the character's goal was to sleep (27 out of 30). One participant stated that his goal was to wake up; two stated that he had no intention. No participants inferred movement-based goals (0 out of 30; see Fig. 5).

#### 3.2.3. Character's intention: Intentional movement condition

In response to the question "What was Tim's intention?", 46.7% of participants in the intentional movement condition inferred a movement-based goal, an incidence similar to that in the objects-absent condition of Experiment 1 (14 out of 30 versus 50 out of 102, $\chi^2 = 0.051$, $df = 1$, two-tailed $p = 0.82$), and significantly higher than that in the unintentional movement condition (14 out of 30 versus 0 out of 30; $\chi^2 = 18.26$, $df = 1$, two-tailed $p < .0001$). 36.7% of participants inferred an external goal, an incidence also similar to that in Experiment 1 (11 out of 30 versus 33 out of 102, $\chi^2 = 0.19$, $df = 1$, two-tailed $p = 0.65$). Two participants inferred that the character intended to dance, and two inferred that he intended to entertain himself. One participant considered more than

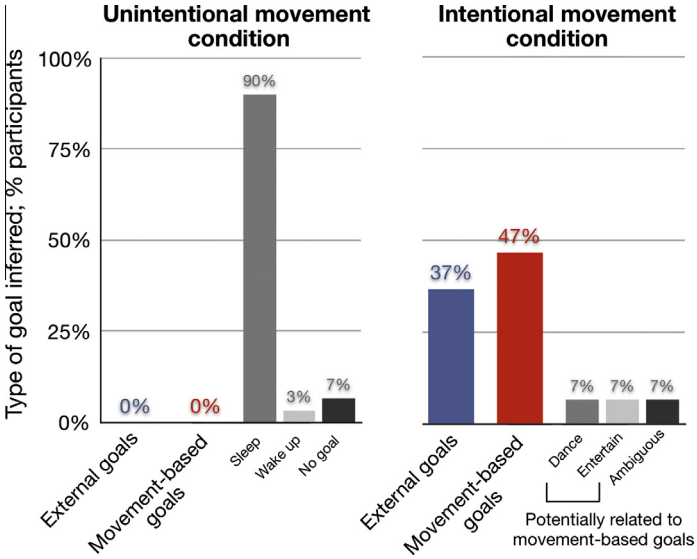


**Fig. 5.** Goals inferred in the unintentional movement condition (left) and intentional movement condition (right), Exp. 2. Despite the fact that observers all saw the exact same sequence of movements, observers in the unintentional condition never inferred movement-based goals, whereas those in the intentional movement condition frequently inferred movement-based goals. Because some participants inferred multiple alternative goals, percentages sum to greater than 100%.

one possible goal, and two gave answers that were ambiguous (see Fig. 5).

*3.2.4. Prediction data: Unintentional movement condition*

In the unintentional movement condition, only 53.3% of participants' expectations were consistent with continuing the movement pattern, a rate no different from chance (16 out of 30 participants, two-tailed binomial test $p = .86$). Specifically, 7 of the 15 participants who saw rightward movement at test said it was what they expected; 6 of the 15 who saw leftward movement said it was what they expected.

*3.2.5. Prediction data: Intentional movement condition*

As in Experiment 1, participants who inferred movement-based goals reliably expected the character to continue the same movement pattern (12 out of 14 participants, one-tailed binomial test $p = .013$). Specifically, 8 of the 9 participants who saw rightward movement at test said that this was what they had expected; only 1 out of the 5 participants who saw leftward movement at test said it was what they had expected.

In contrast, participants who saw exactly the same stimuli but inferred an external goal did not consistently expect that the character would continue in the same movement pattern. Only 54.5% of these participants' expectations were consistent with continuing the movement pattern, a rate no different from chance (6 out of 11 participants, two-tailed binomial test $p = 1.0$). Specifically, 1 out of the 5 participants who saw rightward movement at test said that it was what they had expected; 1 of the 6 participants who saw leftward movement said that it was what they had expected.

We also analyzed the predictions of participants who inferred goals that we hypothesized to be related to movement-based goals. These goal inferences occurred only in the intentional movement condition, and included the goals of dancing and entertaining oneself or others. As in Experiment 1, participants who inferred these goals expected the character to continue the movement pattern (100%, 4 out of 4 participants).

*3.2.6. What was Tim keeping secret?*

In response to the question "What was Tim keeping secret?" no participants stated that the movements were the character's secret, and only 3 of the 60 participants mentioned the character's movements in any form. Forty-two out of sixty participants stated that they did not know the character's secret, or stated that there was no secret (Intentional movement condition: 'Don't know': 7 out of 30; 'None': 14 out of 30; Unintentional movement condition: 'Don't know': 9 out of 30; 'None': 12 out of 30). The remaining 18 of the 60 participants provided a wide range of guesses with no single consistent answer (e.g. "his age", "a secret move", "his dreams"; see Supplemental data).

*3.3. Discussion*

One goal of the current experiment was to test the validity of our goal inference measure, the free-response question "What was Tim's intention?", in order to ensure that when participants respond by describing movements, this actually indicates that they have represented the movements as the goal. We found strong evidence of the validity of this measure. Firstly, we found that movement-based answers are not caused by participants' uncertainty: When faced with a question to which they did not know the answer ("What was Tim keeping secret?"), none of the participants stated that the characters' movements were the answer. Instead, participants

were highly willing to admit uncertainty or to oppose the pragmatics of the question by stating that no answer existed. Second, we found that participants only provide movement-based answers to the "intention" question when the observed movements are intentionally produced. When participants saw the character move unintentionally (due to being pushed by an external object), participants did not answer the "intention" question by describing the character's movements, but often did so for the very same movements when they appeared intentional. These data support the validity of our goal inference measures, and bolster the claim that participants who responded to the "intention" question by describing the character's movements indeed represented the movements as the characters' goal.

Experiment 2 is important beyond this purely methodological point: These data show that for movements to be seen as the goal of an action, the action must appear intentional. Thus, Experiments 1 and 2 together provide evidence for our hypothesis: In these experiments, observers only inferred movement-based goals when the actions were both (1) intentional and (2) not an efficient means to external goals. Thus, observers appear to infer that movements are an agent's goal in order to explain intentional movements that are not an efficient means to any other goal.

Experiments 1 and 2 also rule out several alternative hypotheses regarding what drives people to infer movement-based goals. First, movement-based goals are not simply cued by specific types or amounts of movement: All stimuli in Experiments 1 and 2 contained the same path of movement, yet observers did not infer movement-based goals at equal rates in all conditions. In addition, all stimuli in these experiments were equally patterned and equally repetitive. Thus, although pattern and repetition may have played an important role in observers' reasoning, the presence of pattern and repetition cannot be sufficient to drive the inference that movement is the goal.

However, two alternative hypotheses about what drives observers to infer movement-based goals remain viable. First, we have not yet ruled out the possibility that low-level perceptual differences drive observers to infer movement-based goals. In both Experiments 1 and 2, stimuli were highly different perceptually, due to the presence or absence of objects in the environment. Specifically, in the conditions where participants did not infer movement-based goals, there were salient objects present in addition to the character himself (the boxes and balls in Experiment 1, the apparatus on which the character was sleeping in Experiment 2). In contrast, no objects were present in the conditions in which participants inferred movement-based goals. Without distraction from objects, the observer's attention likely remains more focused on the character's movement throughout the video. This increased attention to movements, driven by the lack of salient objects, could potentially lead observers to infer that the movements are the goal. This 'object salience' hypothesis can be tested by holding the presence and salience of objects constant across conditions, while varying whether the movements are efficient means to an external goal.

Second, other studies suggest an additional competing explanation for the attribution of movement-based goals: The critical factor may be the actions' failure to cause change to the environment. In a related line of work exploring ritual actions, Legare and Whitehouse (2011) have proposed that failure to cause change to the environment triggers a 'ritual stance,' which drives attention to the exact movements performed. According to this proposal, observers in our experiment were not using efficiency to rationally infer the best explanation. Instead, actions' failure to change the environment acted as a direct trigger or cue, drawing attention to movements.

Consistent with this proposal, Legare and Whitehouse report that children copy the movements of an adult model more exactly if the movements do not cause change to the environment (e.g. moving an object but putting it back where it came from) than if similar movements do cause change (e.g. moving an object from one location to another; Legare & Whitehouse, 2011). However, an efficiency account can also explain this finding: The two experimental conditions differed not only in the actions' success or failure to cause change, but also in the actions' inefficiency as a means to an external goal. Specifically, the actions that did not change the environment also were not an efficient means of achieving any external goal. Thus, the children in Legare and Whitehouse's study (like the adults in ours) may have concluded that the person's goal must have been to produce the observed movements. In this case, children's exact imitation may simply be a product of typical goal inference and goal emulation (copying the goal, but not the means; Want & Harris, 2002; Whiten, McGuigan, Marshall-Pescini, & Hopper, 2009): If children believed that performing the specific observed movements was the model's goal, even normal goal emulation would lead children to imitate the movements exactly.

In this prior work as well as in our first experiment, failure to change the environment has always been confounded with inefficiency as a means to external goals. However, these factors can be teased apart, by (a) comparing actions that are equally inefficient as a means to external goals, but either do or do not change the environment, or (b) comparing actions that cause an equal amount of change to the environment, but differ in terms of their inefficiency as a means to external goals.

## 4. Experiment 3

To tease apart whether the inference that movement is the goal is driven by (a) inefficiency as a means to external goals, (b) lack of salient objects, or (c) failure to change the environment, we showed participants one of five animated stimuli, each featuring a character holding a star, and a box with a prominent star on it (see Fig. 6 and Videos 10–14). A first group of participants observed the character jump twice toward the box (1 set of jumps, 'toward-only'). A second group saw the character jump twice toward then twice away from the box, returning to his initial location (2 sets of jumps, 'toward-away'). A third group saw the character produce three sets of jumps ('toward-away-toward'), ending in the same location as in the toward-only condition. A

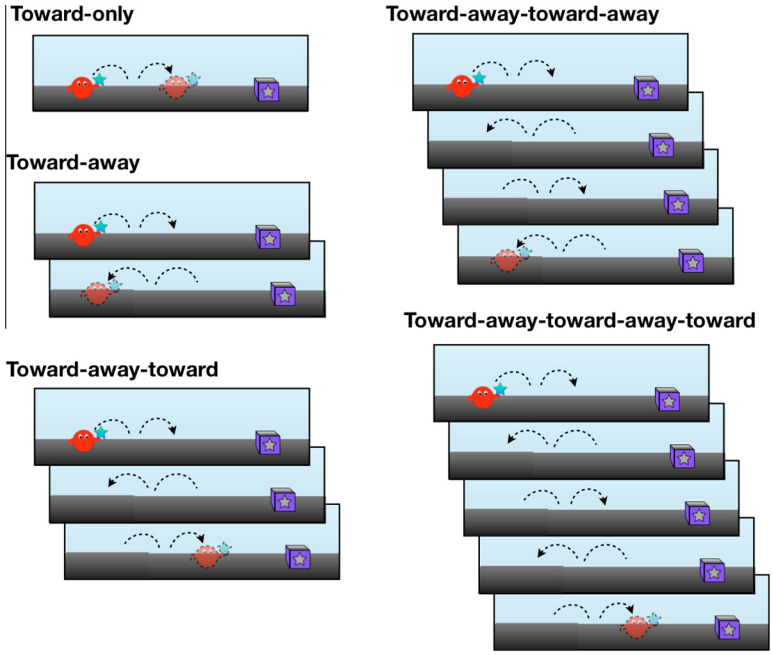


**Fig. 6.** Stimulus videos of the five between-subject conditions, Exp. 3. Arrows represent character's path of movement. Ghosted character represents the character's location in the final frame.

fourth group saw the character produce four such sets of jumps ('toward-away-toward-away'), and a fifth group saw the character produce five such sets of jumps ('toward-away-toward-away-toward'). Afterward, participants described the characters' intention, and we compared how often participants inferred that the goal was to produce the movements in each of these conditions.

Each of the three accounts outlined above makes clear and divergent predictions regarding when participants should infer movement-based goals in this experiment (see Fig. 7a). Under the hypothesized inefficiency account, observers infer that the movements are the goal in order to explain intentional actions that are not an efficient means to any other goal, and thus for which they have no better

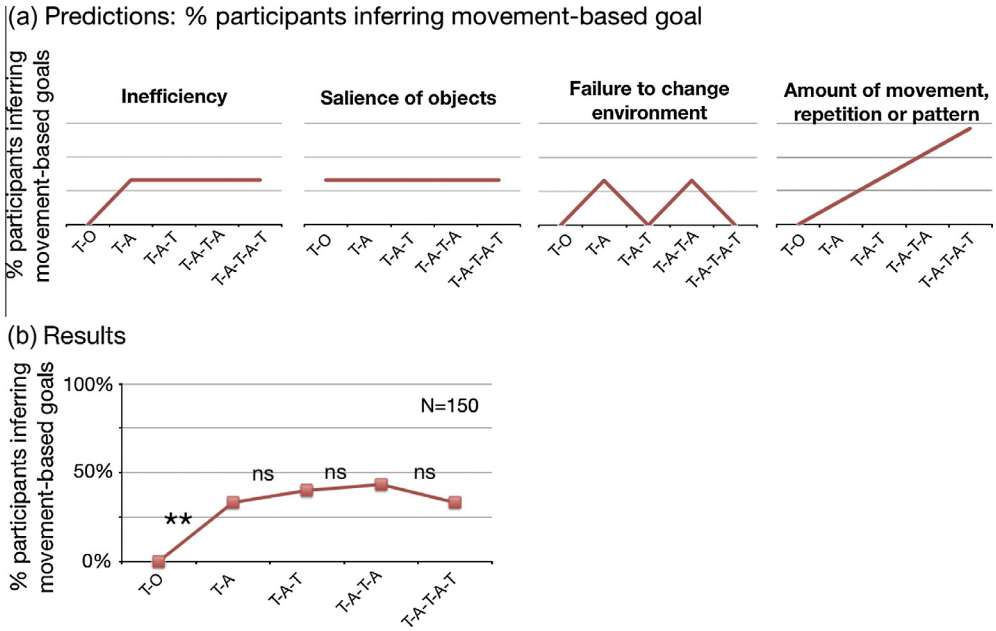


**Fig. 7.** Predictions and results, Exp. 3. (a) Predictions regarding the rate of inferring movement-based goals in the toward–only (T–O), toward–away (T–A), toward–away–toward (T–A–T), toward–away–toward–away (T–A–T–A), and toward–away–toward–away–toward (T–A–T–A–T) conditions, according to the four alternative hypotheses (see text). (b) Results: predicted only by the inefficiency account.

explanation. If this account is correct, observers should not infer movement-based goals in the toward-only condition, because in this case the character takes an efficient path toward the box. In contrast, in the other four conditions, the character also moves away from the box, making the path an inefficient means to the box and leaving no clear explanation for the movements. Thus, if our hypothesis is correct, participants should not infer movement-based goals in the toward-only condition, and should infer movement-based goals at a higher and constant rate in the other four conditions.

In contrast, if failure to cause change in the environment cues the inference, we should find a different set of results: Observers should infer that movements are the goal more often in the toward-away and toward-away-toward-away conditions than in the other conditions. In these two conditions, the agent's starting and ending position are the same, such that in the last frame the entire scene is in exactly the same position in which it began. In contrast, in the other three conditions the characters' starting and ending position differ, changing the environment with regard to the location of the agent as well as the location of the star he is holding. Thus, if the actions' failure to change the environment drives the conclusion that movements are the goal, participants should only infer movement-based goals in the toward-away and toward-away-toward-away conditions; or, if the character's position change is not treated as a true change to the environment, observers should infer movement-based goals equally in all conditions.

Thirdly, if the inference that movement is the goal is primarily driven by the lack of salient objects, the rate of inferring movement-based goals should be equal across all five conditions, as the stimuli all contain the same type and number of objects.

### 4.1. The role of total amount of movement, repetition and pattern

In the first two experiments, the total amount of movement, repetition and pattern was equated across experimental conditions, and yet observers showed dramatically different rates of inferring movement-based goals. These data show that the inference that the movements are the goal is not *solely* driven by the amount of movement, repetition or pattern. However, the amount of movement, pattern or repetition may still affect goal inferences, in conjunction with other factors: Such an effect would only emerge when the total amount of movement, pattern or repetition is not equated.

The current experiment allows us to explore this possibility, and ensure that this factor is not the *only* cause of differential rates of attribution of movement-based goals in the current experiment. Across the five conditions, the total amount of movement produced increases incrementally, at a constant rate, with the addition of each set of jumps. The total amount of repetition and pattern also increases with the addition of each set of jumps. If participants' movement-based goal inferences are driven by the amount of movement, pattern or repetition, then the addition of each set of jumps should lead to a corresponding increase in the rate of inferring movement-based goals across the five conditions (from 1 to 5 sets of jumps).

### 4.2. Method

#### 4.2.1. Participants

154 adult residents of the United States (18+ years of age) took part in the experiment over the internet, via the Amazon Mechanical Turk website using the same qualification procedures as in Experiment 1. 30, 30, 31, 30 and 33 participants took part in the five conditions (from 1 to 5 sets of jumps, respectively); extra participants were run in the toward-away-toward and toward-away-toward-away-toward conditions to equate the number of participants who passed the intentionality manipulation check and thus were included in analyses of goal inference. Six participants were additionally run, but excluded from the final sample due to technical problems viewing the videos (4), leaving answers blank (1), or indicating misunderstanding of instructions (1). Each participant took part in only one condition. Approximately half of the participants in the 4 and 5 sets of jumps conditions were run $\sim$1.5 years after the rest of the participants, to equate sample size across conditions (see Supplemental data).

#### 4.2.2. Stimuli

Each participant saw one of five animated videos. Each video began with a box with a star-shaped label on the right side of the screen, and a character holding a star on the left side of the screen. In the 'toward-only' condition, the character jumped toward the box twice, ending up in a central position, closer to the box than where he started (1 set of jumps). In the 'toward-away' condition, the character jumped twice toward the box, then twice away from the box (2 sets of jumps), ending in the same place he started. In the 'toward-away-toward' condition, the character jumped twice toward the box, then twice away, then twice toward the box again (3 sets of jumps), ending up closer to the box than where he started, and in an identical ending position as in the toward-only condition. In the 'toward-away-toward-away' condition, the character produced four such sets of two jumps each, ending in the same place he started. In the 'toward-away-toward-away-toward' condition, the character produced five such sets of two jumps each, ending closer to the box than where he started, and in an identical ending position as in the toward-only condition (see Fig. 6 and Videos 10–14).

#### 4.2.3. Procedure

Questions and text were identical to that of Experiment 1, except that observers were not shown a second video and asked to predict the character's next action.

#### 4.2.4. Data analysis

As in previous experiments, the question asking whether the actions were intentional or accidental was used as an initial methodological check. Participants were not included in further analyses if they failed the manipulation check (by saying the actions were accidental; this exclusion did not change findings).

*4.2.5. Coding of free-response answers*

As in Experiments 1 and 2, the goal inferred by the participant was determined by coding participants' answers to the question "What was Tim's intention?" into representative descriptive categories. Data was recoded by a second, independent coder for reliability; in rare cases of disagreement, the first coder's designations were used. The two coders agreed on 96.7% of participants' category designations (149/154 participants).

*4.3. Results*

*4.3.1. Intentionality check*

In response to the forced-choice question, 97.4% of participants answered that the actions were intentional, not accidental (150 out of 154, Toward-only condition: 30 out of 30; Toward-away: 30 out of 30; Toward-away-toward: 30 out of 31; Toward-away-toward-away: 30 out of 30; Toward-away-toward-away-toward: 30 out of 33).

*4.3.2. Character's intention: Toward-only condition*

Participants in the toward-only condition inferred external goals, e.g. that the character's intention was to put the star into the box (28 out of 30; see Table 2 and Figs. 7 and 8). No participants inferred movement-based goals (0 out of 30). One participant supplied an answer that was judged ambiguous, and one inferred the goal of entertaining oneself or others.

*4.3.3. Character's intention: Toward-away condition*

10 of the 30 participants (33.3%) in the toward-away condition inferred a movement-based goal. This rate is significantly higher than that in the toward-only condition (0 out of 30 versus 10 out of 30; $\chi^2 = 12.00$, $df = 1$, two-tailed $p < .001$). 12 of the 30 participants (40.0%) inferred external goals, and four participants stated that the intention was to entertain oneself or others. Three participants said that they did not know the character's intention, and one participant's answer was judged ambiguous.

*4.3.4. Character's intention: Toward-away-toward condition*

12 of the 30 participants (40.0%) inferred a movement-based goal. This rate is significantly higher than that in the toward-only condition (0 out of 30 versus 12 out of 30; $\chi^2 = 15.0$, $df = 1$, two-tailed $p < .001$) and not significantly different than that in the toward-away condition (10 out

**Table 2**
Observers' answers to the question 'What was the character's (Tim's) intention?', Exp. 3. Representative examples of answers coded as external goals and movement-based goals from participants in each of the five conditions.

| | What was the character's intention? Representative answers | |
|---|---|---|
| | External goals | Movement-based goals |
| Toward-only condition | He intended to put the star on the box<br>To place the star into the box<br>To get to the box<br>To bounce his way to the other object<br>To move toward the box so he could place the star in it | None |
| Toward-away condition | His intention was to put the star in the box<br>Tim was considering putting his star in the box<br>To throw the star into the box<br>He was teasing the box by taking the star to him and then bouncing away<br>Putting the star in the box | To bounce back and forth<br>To hop<br>To jump around<br>To hop around with the star<br>Jump around with star next to the box |
| Toward-away-toward condition | To get the star to the box<br>To display the star he was holding<br>He was probably going to put the star in the box<br>His intention was to tease the box<br>Not to go near the box<br>Tim intended to carry the star | To hop back and forth<br>To bounce backwards after bouncing forward<br>To move back and forth<br>To jump back and forth while carrying a star<br>I assumed it would be to put the star in the box marked with a star, but his intention seemed to be just to bounce about holding a star |
| Toward-away-toward-away condition | Probably to get people to notice the star in his hand<br>He was thinking about putting the star in the box but hesitating<br>Keep the star to himself<br>To place a star in a box<br>He may have wanted to place the star in the box | To jump around<br>To bounce back and forth<br>Tim just wanted to jump<br>Tim intended to hop because he was happy about having a blue star<br>To bounce...with star in hand<br>Tim's intention was to hop back and forth in a playful manner |
| Toward-away-toward-away-toward condition | To put the star in the box<br>He intended to put the star in the box, however, he may have been scared and so he backed away from the box when he got too close<br>He was trying to reach for the box with the star<br>My guess is Tim wanted to place the star in the box<br>He was attempting to get attention so he could show the blue star in his hand | To bounce around the room<br>In this video, if it is true that Tim's actions were intentional, then the only intention that we could gather from the video is that his intention was to bounce back and forth from left to right<br>To bounce back and forth, holding a star<br>To bounce around<br>His intention was to hop back and forth with a star as if he was doing a victory celebration that he had gotten the star |

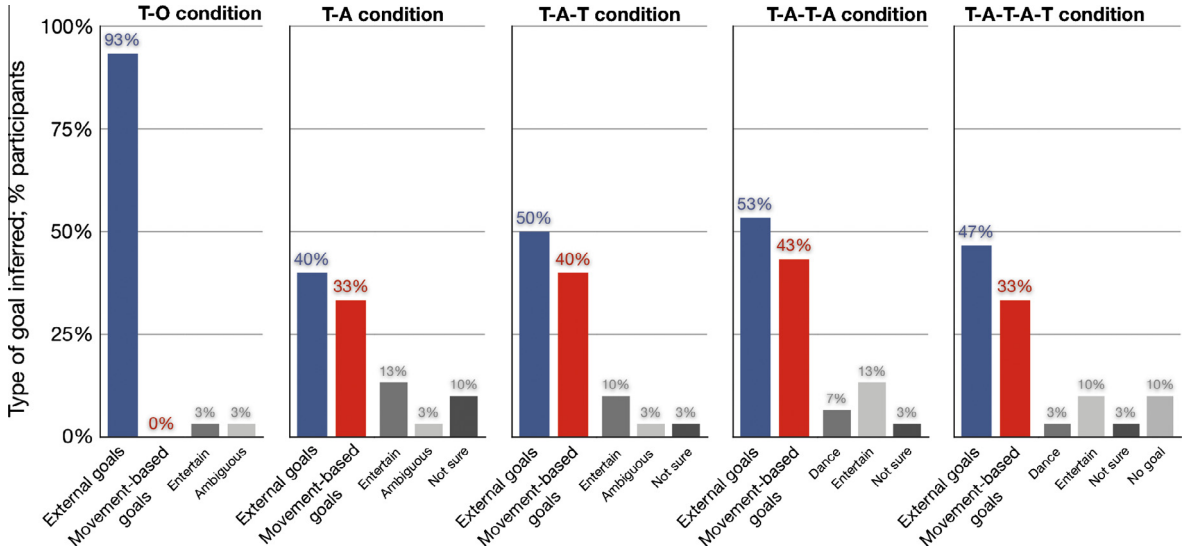


**Fig. 8.** Goals inferred in each of the five conditions, Exp. 3. In the toward-only (T–O) condition, observers never inferred movement-based goals. In the other four conditions, a large proportion of participants inferred movement-based goals. Because some participants inferred multiple alternative goals, percentages sum to greater than 100%. Abbreviations: 'T' = toward, 'A' = away, 'O' = only (e.g. T–A–T = toward–away–toward).

of 30 versus 12 out of 30; $\chi^2 = 0.287$, $df = 1$, two-tailed $p = 0.592$). 15 of the 30 participants (50.0%) inferred external goals, four inferred the goal of entertaining oneself or others, one stated that they did not know the character's intention, and one participant's answer was judged ambiguous. Three participants inferred multiple alternative goals.

#### 4.3.5. Character's intention: Toward-away-toward-away condition

13 of the 30 participants (43.3%) inferred a movement-based goal. This rate is significantly higher than that in the toward-only condition (0 out of 30 versus 13 out of 30; $\chi^2 = 16.6$, $df = 1$, two-tailed $p < .001$) and not significantly different than that in the toward-away or toward-away-toward conditions (10 out of 30 versus 13 out of 30: $\chi^2 = 0.64$, $df = 1$, $p = 0.42$; 12 out of 30 versus 13 out of 30: $\chi^2 = 0.07$, $df = 1$, $p = 0.79$, all two-tailed). 16 of the 30 participants (53.3%) inferred external goals, two stated that the intention was to dance; four stated that the intention was to entertain oneself or others, and one stated that they did not know the character's intention. Five participants inferred multiple alternative goals.

#### 4.3.6. Character's intention: Toward-away-toward-away-toward condition

10 of the 30 participants (33.3%) inferred a movement-based goal. This rate is significantly higher than that in the toward-only condition (0 out of 30 versus 10 out of 30; $\chi^2 = 12.00$, $df = 1$, two-tailed $p < .001$) and not significantly different than that in the toward-away, toward-away-toward or toward-away-toward-away conditions (10 out of 30 versus 10 out of 30, $\chi^2 = 0$, $df = 1$, $p = 1$; 12 out of 30 versus 10 out of 30: $\chi^2 = 0.287$, $df = 1$, $p = 0.592$; 13 out of 30 versus 10 out of 30: $\chi^2 = 0.64$, $df = 1$, $p = 0.42$; all two-tailed). 14 of the 30 participants (46.7%) inferred external goals, one stated that the character's intention was to dance, three stated that the intention was to entertain oneself or others; three said that the character had no intention, and one said that they did not know what the character's intention was. Two participants inferred multiple alternative goals.

### 4.4. Discussion

These results strongly support our hypothesis that an actions' inefficiency as a means to external goals drives observers to infer movement-based goals. In line with this hypothesis, participants in Experiment 3 did not infer movement-based goals when the actions were an efficient means to an external goal (in the toward-only condition), and inferred movement-based goals at a higher and constant rate when the actions were not an efficient means to an external goal (in the other four conditions).

These findings also provide evidence against three alternative accounts of what drives observers to infer that movements are the goal. Firstly, the inference is not driven by the actions' failure to cause change in the environment. If this was the critical factor, we should have seen a higher rate of inferring movement-based goals in the toward-away and toward-away-toward-away conditions than in the other conditions, because in these two conditions the character and objects end up exactly where they started. Alternatively, if the character's position changes are not seen as changes to the environment, we still should have observed equal rates of inferring movement-based goals in all conditions. However, we did not observe either of these patterns: the rate of inferring movement-based goals was lower in the toward-only condition than in the other four conditions, and was higher and constant across the other four conditions. These results show that the inference is not driven by the salience of objects in the environment:

The same objects were present in all conditions, yet we did not see an equal rate of inferring movement-based goals across the five conditions.

Finally, these data show that movement-based goals are not driven by the total amount of movement, repetition or pattern present, at least for the types of stimuli in the current experiment. The amount of movement, repetition and pattern greatly increased from the toward-away to the toward-away-toward-away-toward conditions, yet the rate of inferring movement-based goals remained constant. This finding is consistent with Experiments 1 and 2, in which these factors were equated across all conditions, yet the likelihood of inferring movement based goals differed dramatically. Overall, these three experiments show that the total amount of movement, repetition, or pattern in the stimuli does not explain or predict the circumstances under which observers infer movement-based goals, and support our hypothesis that the actions' inefficiency as a means to external goals drives observers to infer movement-based goals.

## 5. General discussion

The first important finding from these experiments is that there are circumstances under which adults, upon observing the action of an agent, infer that the agent's goal is simply to produce the movements. In this case, the movements themselves are seen as the intended outcome, not just a means to an end. This finding stands in contrast with implicit assumptions in recent developmental literature (e.g. Gergely et al., 1995; Woodward, 1998) and with explicit statements that only actions that efficiently change the environment are seen as goal-directed (Csibra, 2003; Király et al., 2003; Southgate et al., 2008).

These experiments also support our hypothesis as to *when* and *why* people infer movement-based goals, namely, as a means of explaining actions that are clearly intentional, yet are not an efficient means of achieving any plausible external goal. Other goals' failure to explain why the agent is producing intentional movements leads observers to conclude that the agent's goal must have been to produce the movements themselves. In the first experiment, participants only inferred movement-based goals in an objects-absent condition, in which there was no clear way to explain the movements in terms of external goals. Participants never inferred movement-based goals when an external goal was available (in an objects-present condition), in spite of seeing identical movements. In the second experiment, participants only inferred movement-based goals when the actions were intentional, not when they were unintentional, again in spite of seeing identical movements. In the third experiment, participants inferred movement-based goals when and only when the character's actions were not an efficient means of achieving a plausible external goal (e.g. putting a star in a box). The rate of inferring movement-based goals tracked with the inefficiency of the actions when equating for the type of movement, salience of objects, and failure to affect change on the environment; and even across systematic variation in the amount of movement, repetition and pattern.

The finding that movements are only seen as the goal when the movements are inefficient means to other goals is in line with a formal Bayesian analysis of goal inference (Baker et al., 2009). Placing this theory into a formal framework helps explain why movement-based goals appear to start out with a low probability, and only become the best explanation when other goals are unlikely. First, the vast number of individual possible movement-based goals makes each one unlikely, as the total prior probability of movement-based goals (as a class) must be divided among these individual goals. Second, external goals make more specific predictions about the movements expected, and thus will be favored over the general class of movement-based goals if both are consistent with the observed movements (MacKay, 1992, 2003). In line with these predictions of Bayesian inference, participants did not infer movement-based goals when the movements were also an efficient means to a plausible external goal, either in Experiment 1 (objects-present condition) or Experiment 3 (toward-only condition).

Our data rule out a number of alternative accounts of what could drive observers to infer that movements are the goal, including failure to change the environment, and a lack of salient objects in the environment. However, this is not to say that these factors are entirely unrelated to movement-based goal inference: It is likely that these factors typically (although not unavoidably) make it more likely that the movements are not an efficient means to an external goal. For example, failing to change the environment often leaves fewer or less-plausible external goal possibilities. In the same way, a lack of objects leads to fewer plausible external goal possibilities. Thus, we expect that these factors will often be correlated with the tendency to infer movement-based goals. However, the factor which ultimately determines whether movements are seen as the goal of intentional actions appears to be whether the movements are an efficient means of achieving a plausible external goal, or not.

### 5.1. What is the role of pattern?

Pattern and repetition cannot be sufficient to cue movement-based goals: The same patterned movements were present in all conditions of the first and second experiments, yet participants did not infer movement-based goals in all conditions. Adding more pattern and repetition to the movements also did not reliably increase the rate of inferring movement-based goals (Experiment 3). However, these factors may still be playing an important role in observers' goal inferences.

Firstly, the patterning and repetition of the movement sequence may serve as evidence that the actions are intentional and not accidental, since this type of patterned movement is unlikely to occur accidentally. Although a connection between pattern and intentionality has not yet been tested in the domain of actions, an analogous phenomenon has been shown in reasoning about objects. Complex, patterned structure and repetition in an objects' shape appears to provide evidence that the shape is not accidental, but created or selected by some structure-generating process like intentional action (Prasada, Ferenz, &

Haskell, 2002). In addition, infants expect that only animate agents can organize objects in a patterned, orderly fashion, while both animates and inanimates can create disorder (Newman, Keil, Kuhlmeier, & Wynn, 2010). In a similar way, patterning of movements may serve as evidence that the movements are produced intentionally by an animate agent, since these patterns are highly unlikely to be produced by accident or by an inanimate force. One powerful cue to intentionality, reactivity to the environment (Gelman et al., 1995; Tremoulet & Feldman, 2006), is notably absent in the objects-absent/intentional condition of our first and second experiments. Patterning may add evidence of intentionality necessary to replace this missing evidence.

Pattern may also serve as a positive cue that movements are the goal by trading off against efficiency. For instance, pattern and repetition may make movement-based goals more probable by helping to rule out the goal of getting to any specific location. In patterned, repetitive movements, the agent moves not only in a single direction, but also back the way he came, revisiting the same locations more than once. This makes the path an inefficient route to any single location, and potentially rules out the entire class of location-based goals. By ruling out this class of external goals, patterning and repetition may make movement-based goals more likely to be the best explanation.

As a result of the relationship between pattern and inefficiency, an observer may learn (i.e. through experience) that patterned movements tend to have movement-based goals. Thus the observer may infer that patterned actions have an increased probability of movement-based goals. We plan to test these hypotheses about the role of pattern in future experiments.

### 5.2. Movement-based goals as possible basis for concepts of dance, ritual and exercise

In our first experiment, some participants spontaneously inferred that the characters' actions were dance, ritual or exercise in the objects-absent condition, but not in the objects-present condition. These participants subsequently expected the character to continue the same movement pattern. Several participants in the second and third experiments also inferred that actions were dance, again only when the actions were both intentional and inefficient. Thus, the responses of participants who inferred these goals patterned with those of participants who inferred movement-based goals, with respect to (a) the conditions under which these goals were inferred and (b) their predictions of the character's next movements.

This finding suggests that there may be a relationship between the idea of movement as the goal, and higher-level action concepts such as dance, ritual and exercise. These types of actions often appear to involve the goal of producing specific movements, which are often not an efficient means of achieving any external goal. For example, the decorative, intricate gestures of dance are not an efficient means of reaching any object or location, and observers appear to categorize the actions of a person dancing alone in a room as dance, even when these actions do not achieve a communicative or social goal. Lastly, dance, ritual and exercise actions are imitated exactly by those wishing to learn them, as would be the case for actions for which the specific movements are the goal (see below). We are currently conducting additional experiments to further test the relationship between these action concepts and movement-based goals (Schachner & Carey, in preparation, 2011). The current data suggest that the goal of producing specific movements may serve as a conceptual foundation for the concepts of dance, ritual and exercise. This goal inference may then be integrated with other, learned information (e.g. what movement trajectories are typical of dance) to form the adult concepts and differentiate these concepts from one another.

### 5.3. Exact imitation: Emulation of movement-based goals?

When imitating actions, children typically imitate the goals of actions rather than the exact movements they observe, choosing not to copy movements that do not contribute to achieving the goal (e.g. Meltzoff, 1995). However, in some situations children appear to fail to copy in terms of goals, but instead copy the raw movement signal, even when the movements are irrelevant or arbitrary. This phenomenon, termed exact imitation, faithful imitation, or overimitation, has garnered considerable recent interest (e.g. Lyons, Young, & Keil, 2007; McGuigan, Makinson, & Whiten, 2011; Meltzoff & Williamson, 2010; Nielsen & Tomaselli, 2010; Whiten et al., 2009; Williamson & Markman, 2006). Evidence suggests that some cases of exact imitation result from errors in causal analysis: Children may repeat the exact actions because they believe these actions to be causally necessary for achieving a desired goal, such as accessing a toy inside a box (Lyons et al., 2007). The current work suggests an alternative, additional explanation for exact imitation: When children imitate exactly, it may be because they have inferred that part of the other person's goal was to perform those particular movements. In this case, even selective imitation of goals would result in copying the exact movements.[1]

This account of exact imitation provides two testable predictions. Firstly, if people imitate exactly when they infer that the movements are the goal, we should see evidence of exact imitation in adults as well as children. This prediction is borne out by recent data: The phenomenon of overimitation remains and is at least as strong in adults as in children (McGuigan et al., 2011). Secondly, we should see that children are more likely to engage in exact imitation after observing actions that should lead them to infer movement-based goals: Actions which are not an efficient means of achieving any plausible external goal. This prediction is supported by a number of experi-

[1] We expect that children, like adults, should infer movement-based goals for actions that are not an efficient means to an external goal. These actions should include (1) actions that do not achieve any external goal, and also (2) actions that bring about an external goal, but in a clearly inefficient way. In the latter case, we expect that the action may be seen as having two sub-goals: to perform those specific movements, and to achieve some external end, e.g. open the box. Thus we expect that the movements would not be construed as merely a manner or means, but would be part of the intended outcome or goal.

ments in the literature, which employ a manipulation similar to the objects-present versus objects-absent manipulation of our first experiment. These studies show that children and even year-old infants engage in exact imitation more frequently when the movements are not an efficient means of achieving any plausible external goal (Bekkering, Wohlschlager, & Gattis, 2000; Brugger, Lariviere, Mumme, & Bushnell, 2007; Carpenter et al., 2005; Gattis, Bekkering, & Wohlschläger, 2002; Gleissner, Meltzoff, & Bekkering, 2000; Legare & Whitehouse, 2011; Williamson & Markman, 2006; Wohlschlager, Gattis, & Bekkering, 2003). For example, if a model reaches for and grasps one of her own ears, children imitate by grasping the ear on the same side, but often switch which arm is used (ipsilateral or contralateral), thus not imitating the exact movements. However, if the model performs nearly the same movements, but stops just next to each ear and grasps the air, children more frequently imitate the exact movements modeled (Gattis et al., 2002; Gleissner et al., 2000). Similarly, when infants observe a person making a toy mouse hop across a table, either into a house or to the same location without a house present, they imitate the exact movements much more often when the house is not present (Carpenter et al., 2005). In these and other examples (e.g. Brugger et al., 2007; Williamson & Markman, 2006), children imitate the exact movements more often when the movements are not the efficient means to a clear external goal, and imitate exactly less often when there is an external goal present which explains the movement.

Children in these studies may be engaging in the same process of goal inference that we find in adults. Namely, when movements are clearly intentional, yet are an inefficient means of achieving external goals, the children may conclude that the movements themselves are part of the goal. Thus, children may in some cases perform exact imitation not because they are blindly copying, nor because they are mistaken or unsure about which elements of the sequence were causally relevant; but because they saw the movements as part of the goal, and chose to copy that goal.

### 5.4. Infant goal representations: Possible implications

Infants under five or six months of age typically fail to infer external goals, and thus existing literature suggests that these very young infants may fail to represent the notion of 'goal' entirely (Gerson & Woodward, 2013; Sommerville, Woodward, & Needham, 2005). The current work raises a novel possibility: Young infants may be able to represent movement-based goals, even at ages when they fail to infer external goals. Thus, it may be that what is learned in the middle of the first year of life is not the entire concept of 'goal', but simply a new class of goal (interacting with external objects and locations), or even just new prior probabilities for movement-based goals and external goals (learning that external goals are more common than initially believed, and movement-based goals less common).

There are several reasons why infants might represent movement-based goals before external goals, or might place a higher prior probability on movement-based goals. Firstly, very young infants are not yet capable of achieving most external goals, like grasping an object or locomoting to a new location (Adolph & Berger, 2011). Because they cannot successfully engage in these external-goal-directed actions, young infants may fail to represent these goals as a possibility (Sommerville et al., 2005), or may expect external goals to be rare for others as well. Secondly, as young infants learn to control their motor systems, they may regularly engage in movement for its own sake (e.g. the stereotypic, rhythmic movements of neonates; Adolph & Berger, 2011). Based on their own movement-based goal production and lack of external goal production, young infants may expect others to also tend to produce movement-based goals, or may represent movement-based goals at an earlier age than other types of goals.

## 6. Conclusion

In conclusion, we show that observers spontaneously and intuitively infer that the goal of certain actions is to produce the movements themselves. This inference is not driven by low-level perceptual features, such as the trajectory of movement or the salience of objects in the environment, or cued by the movement's failure to cause change in the agents' environment. Instead, the conclusion that movement is the goal appears to be reached through an inferential process, driven by the extent to which the actions are inefficient as means to plausible external goals. When another person's movements cannot be explained in terms of plausible external goals, but appear to be intentional, observers explain the movements by positing that the goal was to perform the movements themselves. This finding expands the current framework for goal inference to account for a new domain of 'irrational' actions, provides a possible conceptual foundation for higher-level action concepts like dance, ritual and exercise, and suggests a novel explanation for overimitation as emulation of movement-based goals.

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## 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.2013.07.006.

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