Acta Psychologica 229 (2022) 103704

Contents lists available at ScienceDirect

Acta Psychologica

journal homepage: www.elsevier.com/locate/actpsy

Moving targets in space: Movement distance as a predictor for experiences of movement agency

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ARTICLE INFO

Keywords:
Sense of agency
Movement
Causation

ABSTRACT

Previous research indicates that the experience of agency over one's actions and movements is influenced by movement predictability as well as movement distance (Hon, Seow, & Pereira, 2018). Addressing previous limitations, we present a compelling test of the relation between movement distance and movement agency. Participants in two studies moved targets predictably or unpredictably, and for short, medium, or long distances. Following prior research, distractor cues moved in the opposite direction of the targets. Results showed that movement agency scores were higher for predictable compared to unpredictable movements. Results also consistently showed that when movements were predictable, longer distances by either the target or the distractor cues increased agency relative to shorter distances. Our findings replicate and extend previous findings showing that stimulus movement distances influence judgments of movement agency.

"I move, therefore I am."

- Haruki Murakami, 1Q84

1. Introduction

Humans engage in intentional actions, which enable them to manipulate and control their environment to attain specific goals. Intentional action is usually accompanied by a sense of agency, which is particularly important in order to assess who is causing what in a complex social situation. Imagine having fun in a snowball fight, and having the distinct feeling of throwing a snowball in someone else's face. In such an exhilarating and perceptually rich social situation, one may wonder how our mental system is able to deduce which snowball was ours and which snowballs were thrown by others. Do such judgments emerge as a function of the direction of snowball movements? Is how far away the snowballs land *the* important predictor in such an assessment? Perhaps we can identify our snowballs by contrasting their movements with the movements of other snowballs flying all around. The central question therefore is: When exactly is it that we attribute the movements of objects to our actions, and when are we more likely to attribute such object movement to the actions that other individuals performed?

In the last two decades, the empirical work on the experience of agency has shown that attributing actions and outcomes to oneself emerges as an outcome of complex psychological processes (Blakemore, Wolpert, & Frith, 2002; Frith, 2005; Wegner & Wheatley, 1999). Indeed, numerous studies have revealed that a variety of internal and external factors contribute to the agency experience (e.g., Aarts, Custers, & Wegner, 2005; Damen, van Baaren, Brass, Aarts, & Dijksterhuis, 2015; Farrer, Bouchereau, Jeannerod, & Franck, 2008; Knoblich & Repp, 2009; Moore, Wegner, & Haggard, 2009; Sato & Yasuda, 2005; van der Weiden, Ruys, & Aarts, 2013; Wegner, 2017; Wegner, Sparrow, & Winerman, 2004; Wenke, Fleming, & Haggard, 2010). The research in this domain typically explores agency through paradigms that feature discrete action-outcome sequences, such as pushing a button and then presenting a sound. In contrast, less attention has been given to movement, and even less so to the movements of objects.

There are however many events in daily life in which people act and subsequently perceive objects moving in space. For example, when working on a computer, people move the cursor on the computer-screen by using a mouse. Or in the context of leisure time and recreation, people often engage in sport activities in which they throw a ball to others. In such cases, action starts with a motor command initiating body movement – of fingers, hand and arm – but is also followed by the movement of an object to its destination. This action event likely feels fully resolved when the object in question reaches its destination. As a consequence, computations of agency may often extend beyond the completion of

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https://doi.org/10.1016/j.actpsy.2022.103704
Received 24 February 2021; Received in revised form 15 July 2022; Accepted 4 August 2022
Available online 11 August 2022

motor movements and include input relating to object movement. The present paper addresses the importance of surrounding object movements when establishing a sense of agency.

In a recent study, Hon, Seow, and Pereira (2018) took a first step to investigate object movements as action outcomes. In their study, participants used key presses to move centrally presented targets (red rectangles) up and down on a computer screen. At the same time, participants were presented with distractor cues referred to as non-targets (blue rectangles) that moved either in the same direction, the opposite direction, or did not move at all. As expected, when the targets moved compatible with the key press direction (e.g., up press/movement up) participants reported increased agency for the target's movements compared to when target-movements were incompatible with the key press direction (e.g., up press/movement down). Interestingly, an interaction effect between target movement compatibility and non-target movement conditions emerged. Specifically, when targets moved compatible, agency was weaker when there were also non-target cues that moved in the same direction as the target. Alternatively, agency was stronger when non-target cues moved in the opposite direction as the target. Fig. 1 presents an overview of the methodology and results by Hon et al.' (2018).

Hon et al. (2018) explained the influence of the non-target movements using a *predictive coding account* that involved spatial distance. Specifically, they argued that prior to a participant moving the target rectangle through a button-press, outcome predictions are generated that involve directionality of the movement and relative distance compared to other cues, such as the non-targets. In other words, an end state is predicted in which targets have spatially separated from other cues. Because the distances between the targets and the non-target cues end up being the largest when targets and non-targets move in opposite directions, a strong match between prediction and outcome is argued to occur, causing a high sense of agency. Likewise, if the targets and non-targets move in the same direction, the predicted increase in distance between targets and non-targets does not occur. Consequently, there would be a weaker match between predictions and outcomes, and therefore also a lower sense of agency. Such logic is largely[1] in line with the motor prediction account of agency, according to which a forward model predicts the sensory consequences of acting prior to the initiation of said action. The model assumes that agency is experienced when there is a match between the predicted outcomes and the actual outcomes of a performed action (Blakemore et al., 2002; Blakemore, Wolpert, & Frith, 2000; Wolpert, 1997).

The spatial prediction account provides a plausible explanation for movement agency (although see Kawabe, 2013). However, in the paradigm used by Hon et al. (2018), spatial distance is potentially confounded with target/non-target movement compatibility. Specifically, there were no incremental manipulations of movement distance. Instead of movement distance being the critical factor, perceiving the stimuli to move in a similar or dissimilar manner may have driven the effects. Specifically, contrasting movements are more likely to stand out than movements that ‘go with the flow’. Consequently, allowing distance and non-target movement compatibility to systematically covary, makes it difficult to establish whether agency was influenced by distance, non-target movement compatibility, or both.

1.1. The present research

Building on the work by Hon et al. (2018), we manipulated target and non-target travel distance while controlling for non-target movement compatibility. Our two studies feature methodology similar to Hon and colleagues: Participants were presented with a target and co-occurring non-target cues, were instructed to move the target cue by pressing a button (the target would move compatible or incompatible to the indicated key press direction), and participants reported their judgments of agency for the target's movement.

In Study 1 we manipulated movement distance in a context in which only the targets moved. We expected that compatible target movements would lead to increased agency experiences compared to incompatible movements. Furthermore, in line with the findings reported by Hon and colleagues, we expected that longer distances would lead to higher agency judgments compared to shorter distances, but only within the compatible movement condition. In Study 2 we examined how experienced agency of target movement changed when both target and non-targets moved over shorter and longer distances. Importantly, non-targets always moved in the opposite direction of the target movement, thus allowing for a test in which experienced agency over target movement was a function of the distance between two moving (target and non-target) objects.

2. Study 1

2.1. Methods

2.1.1. Participants

Thirty-three individuals (19 males; $M_{\text{age}} = 23.76$) participated at Utrecht University's Social Sciences' lab in exchange for course credit or a financial reimbursement equaling five Euro's. This sample size was close to the sample size by Hon et al. (2018; $N = 29$) allowing for attrition. A power analysis (G*Power: Faul, Erdfelder, Buchner, & Lang, 2009) indicated that this sample size was proper given that fifteen participants were minimally required to detect a within-subjects effect in an analysis that involved six levels, a 1 % alpha-level, 80 % statistical power, and an effect size of $\eta_p^2 = 0.23$ (Hon et al., 2018). The research was approved by the Utrecht University's faculty ethics review board. All data and script files can be found at the Surfdrive repository of Utrecht University following the link on the present paper's title page.

2.1.2. Task

Participants were informed they would see colored rectangles appearing on their monitor that could move in predictable and unpredictable directions as a consequence of participants' key presses. It was their task to remain focused on the red rectangle and report their feelings of control (i.e., agency) regarding the red rectangle's movements.

On each trial, participants were presented with one red rectangle target in the center of the monitor, and two blue non-target rectangles that were presented to the left and to the right of the target. Participants performed self-initiated and self-decided up or down arrow key presses. The target rectangle started moving a hundred milliseconds after a key press, either compatible or incompatible with the key press direction. The blue non-targets never moved. After the target rectangle had stopped moving, participants reported to which extent they *felt* that their key press had caused the red rectangle's movement using a 9-point Likert-type scale ranging from 1 (*Not at all*) to 9 (*A lot*).

Participants started with 20 practice trials in which the targets always moved in a direction that was compatible with the direction indicated by the key press. In these practice trials, the distance that the red targets traveled equaled 30 % (i.e., medium distance) of the monitor's vertical axis (movement duration was 80 ms). The subsequent main task consisted of three 60-trial blocks, totaling 180 trials. Targets moved in a direction that was either compatible or incompatible with the direction indicated by the key press. The distance the red targets traveled equaled 15 %, 30 %, or 45 % (i.e., short, medium, or long; for 80 ms, 120 ms, or 160 ms respectively) of the monitor's vertical axis. Trials were presented in random order, but conditions were equally divided across trials. Participants could take a short pause in-between blocks. Fig. 2 depicts the distance conditions of Studies 1 and 2 respectively.

[1] One important caveat here is that motor prediction studies typically address the *probabilities* of different outcomes, whereas the study by Hon et al. (2018) focusses less on probability and more on magnitude. We come back to this issue in the general discussion.

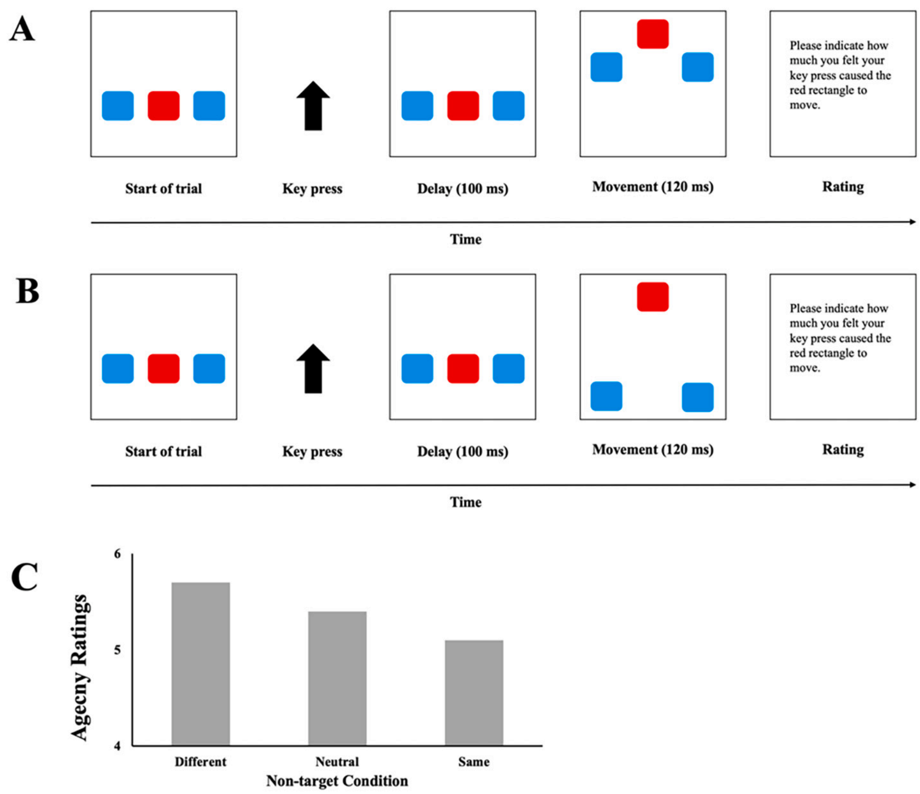

Fig. 1. Design and results by Hon et al. (2018).
Note: A: Compatible target movement, similar non-target movement. B: Compatible target movement, dissimilar non-target movement. C: Effects of distance/non-target movement condition within the compatible target movement condition.

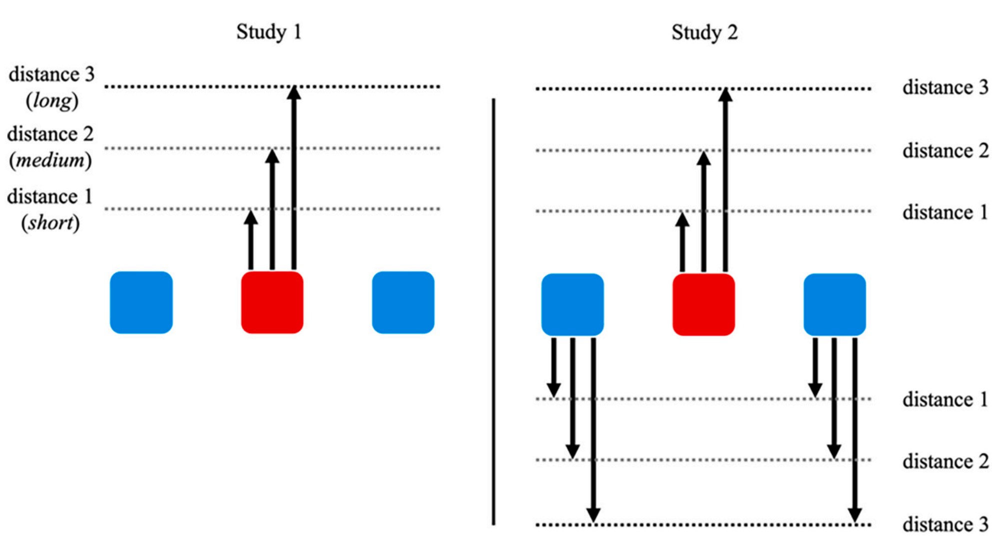

Fig. 2. Distance conditions featured in Studies 1 and 2.
Note. The left panel depicts how in Study 1 a red target moved for a short, medium, and long distance. Blue non-targets never moved in Study 1. The right panel depicts how in Study 2 both the red target and blue non-targets moved for short, medium, and long distances. Blue non-targets always moved in opposite direction of the red target. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

2.2. Results and discussion

A 2 (target movement: compatible vs. incompatible) × 3 (target distance: short vs. medium vs. long) Repeated Measures Analysis of Variance (ANOVA) showed that compatible target-movements increased agency compared to incompatible movements ($M_{Compatible} = 6.747$; $SE = 0.314$ vs. $M_{Incompatible} = 2.894$; $SE = 0.311$, $F(1,32) = 108.395$, $p < .001$, $\eta_p^2 = 0.772$). No main effect of target distance was observed, $F(2,32) = 2.196$, $p = .120$, $\eta_p^2 = 0.064$. Crucially, the analysis showed a significant interaction effect between the target movement compatibility and distance conditions, $F(2, 32) = 4.890$, $p = .011$, $\eta_p^2 = 0.133$. Whereas increased distance increased agency when target movements were compatible, $F(2, 64) = 4.110$, $p = .021$, $\eta_p^2 = 0.114$, such effect of distance was fully absent when target movement was incompatible, $F(2, 64) = 0.215$, $p = .807$, $\eta_p^2 = 0.007$. Results are visualized in Fig. 3.

In short, the findings of Study 1 show that when participants caused targets to move in predictable directions, movements that were farther away led to stronger agency judgments compared to closer movements. In Study 2 we further explored the effects of object movement predictability and distance in a paradigm featuring non-target movements.

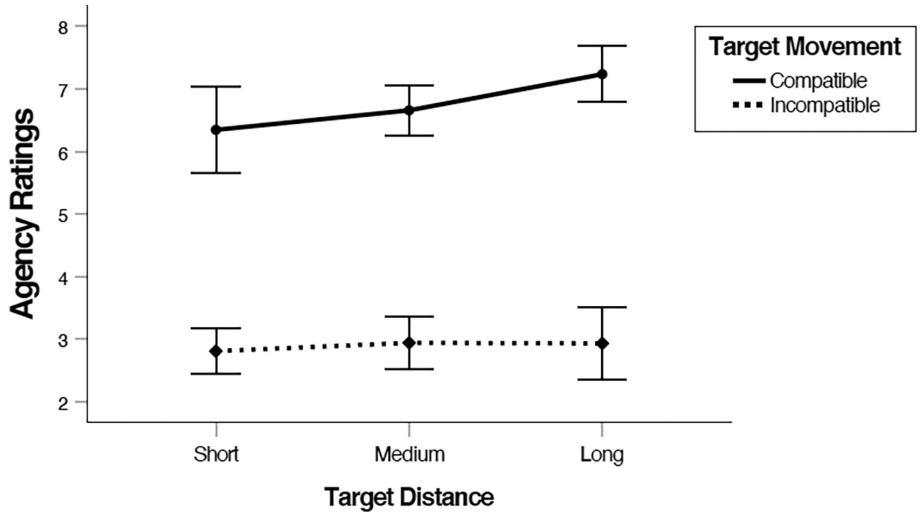

Fig. 3. Mean agency ratings per target movement compatibility and distance.
Note: error bars represent 95 % within-subjects confidence intervals (Cousineau, 2005; Morey, 2008).

3. Study 2

3.1. Methods

3.1.1. Participants

Thirty individuals (19 males; $M_{age} = 33.77$) participated in this study in exchange for five euro or course credit. Participants were recruited through Prolific.ac, an integrated participant recruitment and compensation system that is both diverse and reliable (Peer, Brandimarte, Samat, & Acquisti, 2017). Studies were conducted using the online environment of Inquisit 4.0.2. The research was approved by the Utrecht University's faculty ethics review board.

3.1.2. Task

Similar to Study 1, participants made self-initiated up or down arrow key presses and were presented with twenty practice trials in which targets moved compatible for a medium distance whereas the non-targets remained stationary. As in Study 1, participants saw the red rectangle move a short (distance 1), medium (distance 2), or long distance (distance 3) in either a compatible or incompatible direction with the direction of their key press. Again, participants reported their experienced agency for the red rectangle's movement when that movement was completed. However, in Study 2's main task the adjacently presented blue non-targets also moved. The non-targets always moved in the opposite direction of the target and varied in travel distance: Non-targets moved short (distance 1), medium (distance 2), or long distances (distance 3). This way, the total distance between target and non-targets could vary between 2, 3, 4, 5 and 6 units of distance. Distances and movement durations were equal to the parameters used in Study 1 (short: 15 %, 80 ms; medium: 30 %, 120 ms; long: 45 %, 160 ms). The experiment was again divided into three separate blocks: After the first and second block participants were able take a short break. After the third block and a total 270 trials the experiment ended, and participants were thanked and debriefed. Fig. 2 depicts Study 2's procedure.

3.2. Results

3.2.1. Target vs. non-target distance

The main hypothesis to be tested concerned the effects of absolute distance between target and non-target on experienced agency. Therefore, for each trial we computed the number of positions of the distance between the target and non-targets at the end of movement. Minimum distance (i.e., distance 2) was achieved when targets and non-targets both moved 1 distance from each other. Maximum distance (i.e., distance 6) was achieved when targets and non-targets both moved 3 units of distance. These computations resulted in 5 distances, each separated by a distance equal to 15 % of the monitors height.

We conducted a 2 (target movement: compatible vs. incompatible) × 3 (target/non-target distance: distance 2 vs. distance 3 vs. distance 4 vs. distance 5 vs. distance 6) Repeated Measures ANOVA. This analysis showed that variance on the agency measure was significantly predicted by the main effects (target movement, $M_{\text{Compatible}} = 6.592$; $SE = 0.330$ vs. $M_{\text{Incompatible}} = 3.795$; $SE = 0.396$, $F(1, 29) = 35.731$, $p < .001$, $\eta_p^2 = 0.552$; distance, $M_{\text{Distance 2}} = 4.362$; $SE = 0.316$ vs. $M_{\text{Distance 3}} = 4.833$; $SE = 0.282$ vs. $M_{\text{Distance 4}} = 5.219$; $SE = 0.279$ vs. $M_{\text{Distance 5}} = 5.598$; $SE = 0.322$ vs. $M_{\text{Distance 6}} = 5.956$; $SE = 0.376$, $F(4, 116) = 13.914$, $p < .001$, $\eta_p^2 = 0.324$). More importantly, the analysis revealed a significant interaction between the movement compatibility and distance conditions, $F(4, 116) = 14.236$, $p < .001$, $\eta_p^2 = 0.329$. Whereas increased distance led to increased agency when target movement was compatible, $F(1.135,$[2] $32.920) = 30.991$, $p < .001$, $\eta_p^2 = 0.517$, no effects of distance emerged when target movement was incompatible, $F(1.080, 31.332) = 2.581$, $p = .116$, $\eta_p^2 = 0.082$. Results are visualized in Fig. 4.

In a subsequent analysis we further explored the relative movement of targets compared to non-targets. In some specific contrasts, equal distance outcomes are achieved through different travelling distances of the targets versus non-targets. For example, a distance outcome of 5 spaces can be achieved by having the targets travel 3 spaces and non-targets travel 2 spaces, or alternatively, by having the targets travel 2 spaces and non-targets travel 3 spaces. The question then is, does it matter if it is the target is the farthest moving object or if the non-target is the farthest moving object. We compiled the contrasts yielding equal outcome distances and found that when targets moved compatible, farther target movement was related to higher agency ratings compared to farther non-target movement ($M_{\text{Farther Target}} = 6.926$; $SE = 0.356$ vs. $M_{\text{Farther Non-Target}} = 6.236$; $SE = 0.337$, $F(1, 29) = 11.477$, $p = .002$, $\eta_p^2 = 0.284$). This confirms that the behavior of targets was more important to the computation of agency compared to the non-targets. Finally, and in line with previous results, no differences were observed when the targets moved in an incompatible direction, $F < 1$, n.s.

[2] A Greenhouse-Geisser correction was applied due to a violation of sphericity.

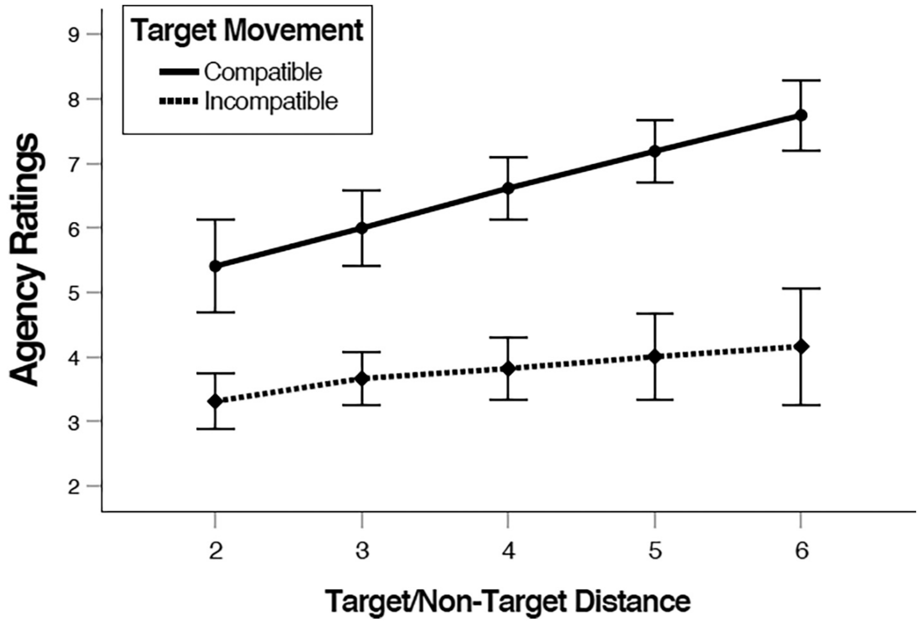

Fig. 4. Mean agency ratings per target movement compatibility and target/non-target distance.
Note: Error bars represent 95 % within-subjects confidence intervals (Cousineau, 2005; Morey, 2008).

3.2.2. Testing agency effects in the full crossover design

We also tested the effects on experienced agency by analyzing the full crossover design, consisting of 18 cells. A 2 (target movement: compatible vs. incompatible) × 3 (target distance: short vs. medium vs. long) × 3 (non-target distance: short vs. medium vs. long) repeated measures ANOVA showed that variance on the agency measure was significantly predicted by all three main effects: Compatible target movements increased agency compared to incompatible target movements ($M_{Compatible} = 6.598$; $SE = 0.330$ vs. $M_{Incompatible} = 3.811$; $SE = 0.398$, $F(1, 29) = 35.210$, $p < .001$, $\eta_p^2 = 0.548$), longer target distances increased agency compared shorter target distances ($M_{Long} = 5.734$; $SE = 0.350$ vs. $M_{Medium} = 5.276$; $SE = 0.284$ vs. $M_{Short} = 4.603$; $SE = 0.284$, $F(2, 58) = 13.368$, $p < .001$, $\eta_p^2 = 0.316$), and longer non-target distances increased agency compared to shorter non-target distances ($M_{Long} = 5.407$; $SE = 0.295$ vs. $M_{Medium} = 5.239$; $SE = 0.279$ vs. $M_{Short} = 4.967$; $SE = 0.297$, $F(2, 58) = 5.525$, $p = .006$, $\eta_p^2 = 0.160$).

Crucially, these effects were qualified by two 2-way interactions. First, there was an interaction between the target movement compatibility and target distance conditions. Specifically, target distance influenced agency only in the compatible movement condition, $F(2, 58) = 30.823$, $p < .001$, $\eta_p^2 = 0.515$, not in the incompatible movement condition, $F(2, 58) = 2.175$, $p = .123$, $\eta_p^2 = 0.070$. Second, there was another interaction between target movement compatibility and non-target distance conditions, $F(2, 58) = 6.048$, $p = .004$, $\eta_p^2 = 0.173$. Specifically, non-target distance influenced agency only in the compatible movement condition, $F(2, 58) = 10.365$, $p < .001$, $\eta_p^2 = 0.263$, not in the incompatible movement condition, $F(2, 58) = 1.501$, $p = .231$, $\eta_p^2 = 0.049$. The two main effects of target and non-target distance in the compatible movement conditions support an absolute distance account, according to which participants assign weight to the two types of distance independently when assessing their experiences of agency.

4. General discussion

Expanding on a recent investigation by Hon et al. (2018), our studies were designed to establish whether agency for the movement of objects is determined by the distance objects moved. It was revealed that when participants moved targets in predictable directions, farther target movement distances were associated with increased agency judgments. This supports the hypothesis that spatial distance is indeed an important parameter for the assessment of movement agency. As recently argued by Hon and Sim (2020) “the greater the separation between the final and start locations, the clearer the evidence of a match between predicted and actual outcomes and, consequently, the greater the sense of agency experienced” (p. 4). The present research extends previous research by controlling for target non-target movement compatibility, and thereby provides further support for the effects of spatial distance on movement agency.

A study by Kawabe (2013) explored the relation between movement speed and agency and found when participants moved dots through their button-presses, that faster dot movements led to higher agency ratings. Kawabe argued that independent from motor prediction, people are likely to retrospectively infer greater control after observing a more powerful or distinct effect of their actions. Although the case can be made that movement speed is likely part of the prediction model, Kawabe's explanation represents an important and alternative account to the prediction model of movement agency. At minimum it would seem fair to say that the intensity or magnitude of the action effect (distance or speed) is an important factor for agency judgments.

In the present studies we manipulated the distance targets and non-targets would travel. As such we were required to choose to either keep travel speeds constant across conditions but allow diverging movement durations, or to keep movement durations consistent but accept diverging travel speeds. Given the effects of movement speed on agency (see the above paragraph), we chose to keep movement speed constant. Although in this setup the time between action resolution and agency judgment is consistent across trials, the time between action initiation and agency judgment varies. Consequently, if participants happen to reflect on agency before the resolution of the action-event sequence, they have more time to do so when distances are longer. While it is unclear if this happened in the present study and if this indeed influences agency judgments, it is important to acknowledge that it could.

Participants in the present study were instructed to focus on the red target rectangle and to reflect on their feelings of control involving the target's movement. Intriguingly, non-target travel distance also significantly impacted agency as the farther the non-targets moved the higher participants judged their agency over their own target movements. Although we use the term non-targets in the present manuscript, it may be more prudent to describe them as secondary targets. It is important to remember though, that target movement appears have much stronger effects on agency than movement of secondary/non-targets (three times as much, roughly speaking when considering the effect sizes).

It would be very interesting for future research to explore the influence of distractor stimuli, by manipulating their reliability (e.g., via action outcome contingencies), their movement congruency, or by diminishing the relation between participants' actions and non-target movements (e.g., embedding a short delay between button-presses and non-target movements). Another option is to have non-targets move sideways, as an additional control and/or to ensure that the non-target movements are less predictable and more strongly conceptualized as irrelevant by the participants. Finally, it would be interesting to explicitly manipulate what the non-targets represent to participants: If participants were told that the non-targets represent objects moved by other agents, would the notion of going with or against others lead to stronger effects?

Overall, the present research solidifies Hon et al.' (2018) basic finding that when target movements are compatible, longer distances between targets and non-targets are related to increased agency judgments. As such it explored a scarcely investigated topic: Object movement agency. Our results suggest that if we, through our actions, move objects in predictable ways, that the further we perceive those objects to move relative to other objects, than the stronger our judgments of agency will become.

Data availability statement

All data and script files can be found at the Surfdrive repository of Utrecht University: https://surfdrive.surf.nl/files/index.php/s/84yFBFVSHiDQZr5

Declaration of competing interest

All authors declare that they have no conflicts of interest.

Acknowledgements

We would like to thank Isabella Klaassens for helping with the running of the studies.

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