Children's Predictions and Recognition of Fall: The Role of Object Mass

Abstract

A small but growing body of evidence suggests that alongside misconceptions in predictions about object motion, adults and children hold relevant underlying conceptions, reflected in recognition, which provide greater understanding of such events. However, the relationship between knowledge retrieved in predictions and in recognition is unclear. One significant element contributing to misconceptions about motion is object mass. This aspect was used to provide further insight into the knowledge relationship. Predictions and recognition of fall in 5- to 11-year-old children (*N* = 121) were addressed in the present study. The results suggest that children's recognition of object motion is far better than their expressed anticipation of such events, as they normally recognised correct events as correct and rejected incorrect ones yet predictions were typically in error. Response time data provide additional insight. The findings are discussed in relation to different models of knowledge representations, favouring a hybrid model.

Keywords: Conceptual development; everyday physics; object fall; object mass

1. Introduction

From a young age children hold extensive but largely erroneous beliefs about the physical world, beliefs which they construct on the basis of personal experiences (Klaassen, 2005). A myriad of studies is available (see Duit, 2009, for a comprehensive list), documenting the wide range of misconceptions present in childhood. Among these are beliefs about dynamic events involving objects, a particularly ubiquitous element of the physical world (Planinic, Boone, Krsnik, & Beilfuss, 2006). These beliefs are not isolated ideas but conceptual structures that can be called upon in reasoning and that, despite their limitations, provide a coherent framework for understanding the world. A prominent view is that we hold innate core knowledge about the physical world that is enhanced over time (e.g. Baillargeon & Carey, 2012; but also see e.g. Hood & Santos, 2009, for a wider discussion around the origins of such knowledge).

Accessing relevant conceptual knowledge structures in motion prediction tasks that are coupled with explicit explanations – such as planning motion trajectories or deciding the location of an object following an anticipated path – necessitates deliberation, reflection, and a conscious understanding of rules or decisions (Hogarth, 2001; Plessner & Czenna, 2008): an explicit engagement with the structures is required. At the same time, a small but growing field of research suggests infants (Friedman, 2002; Kannass, Oakes, & Wiese, 1999; Kim & Spelke, 1992), children (Howe, Taylor Tavares, & Devine, 2012, 2014; Kim & Spelke, 1999) and adults (Kaiser & Proffitt, 1984; Kaiser, Proffitt, Whelan, & Hecht, 1992; Naimi, 2011; Shanon, 1976) are able to recognise dynamic trajectories that are physically correct and to reject trajectories that appear unnatural to them, even if they are more likely to predict the unnatural events beforehand. Such recognition tasks may merely need to engage underlying tacit knowledge structures (Collins, 2010) – structures set to provide quick responses without conscious awareness, by eliciting feelings of familiarity with events. Although there is some indication that very young children engage in predictive anticipation when evaluating outcomes of dynamic events (e.g. Lee & Kuhlmeier, 2013) it is debatable whether these anticipations can be seen as *explicit* predictions since these children eventually chose an incorrect response – likely through some process of reflection and deliberation – despite very initially displaying accurate looking, which may be accounted for by quick responses without conscious awareness.

Currently, there are at least three divergent views on the relationship between these two manifestations of knowledge. Firstly, explicit understanding is perceived to be a partial version of tacit knowledge whereby the two exist within a single system (Kim, 2012; Kim & Spelke, 1999; Spelke & Hespos, 2001). Specifically, in the process of elevating tacit conceptions to the explicit level, elements are omitted, causing differences in outcomes between tasks relying on different knowledge. According to the second view, on the other hand, explicit and tacit knowledge are two mutually exclusive coexisting systems, seemingly unaffected by each other (Hogarth, 2001; Plessner & Czenna, 2008). Depending on task requirements only one of the systems is accessed. The more recent third view rejects omission and separation, and proposes a hybrid model in which there are two, partially associated knowledge systems wherein explicit knowledge is, in part, an embellishment of knowledge held at the tacit level (Carey, 2009; Howe, 2014; Howe et al., 2012, 2014). There is to date no clear evidence favouring just one of these views – a shortcoming addressed by the present research.

Object mass, being one of the most fundamental concepts of the physical world (Galili, 2001), may help shed light on this matter. It is a concept that appears to be in place early in development; the general ability to distinguish between heavy and light emerges within the first year of life (Hauf & Paulus, 2011; Hauf, Paulus, & Baillargeon, 2012; Molina, Guimpel, & Jouen, 2006; Molina & Jouen, 2003; Paulus & Hauf, 2011). Furthermore, this particular concept plays a key role in the development of commonsense theories of motion, as children rely upon mass to explain their predictions of fall – many children hold the persistent belief that one object will fall faster than another because the first is heavier than the second (Baker, Murray, & Hood, 2009; Chinn & Malhotra, 2002; Hast & Howe, 2012, 2013a; Nachtigall, 1982; Sequeira & Leite, 1991; van Hise, 1988). Given the ubiquity of dynamic events, as well as the early developing understanding of the concept of mass, that inform everyday experiences, these limitations in understanding of object motion might seem surprising.

The importance of object mass in the current context therefore lies with the fact that it has, in actuality, little effect on motion patterns – two balls of same size but different mass will move at almost identical speeds – thereby becoming irrelevant to recognition tasks. An ability to recognise events as correct where objects move at the same speeds would suggest that recognition is not susceptible to interference from object mass concepts. This in turn would imply that predictive beliefs are a result of independently existing structures or of embellishment of underlying conceptions rather than omission. Research with adults suggests that expectations specifically relate to mass – a heavy ball is expected to fall faster than a light ball – but acceptance of such motion patterns as correct is much lower, with a tendency towards a more accurate representation of object motion (Naimi, 2011). Children also expect items to fall faster than others because they are heavier – but can similar mass-based differences between prediction and recognition be observed during childhood?

Three hypotheses can be stated to address each of the three divergent views outlined above. In all three cases, based on the literature, the anticipated outcome is that children will *predict* (P) the heavy ball (H) to be faster, with next to no light-faster (L) or same-speed (S) predictions (P = H>L=S). The omission view would envisage a *recognition* (R) task outcome where factors in addition to mass are being taken into account. If other object variables such as size and shape are controlled for this should lead to a similar outcome as in predictions since mass would continue to be a part of the process (R = H>L=S). On the other hand, under the proviso that underlying knowledge is highly accurate, the separate systems view would dictate a distinct set of recognition task findings. Same-speed trials would be uniquely recognised as being correct; heavy-faster and light-faster trials would be rejected in equal manner (R = S>H=L). Finally, if knowledge representations exist within a hybrid model high success rates on same-speed trial recognition should be anticipated but, in line with predictions, also some heavy-faster trial recognition that significantly exceeds that of light-faster trials (R = S>H>L). The study described below was an attempt to assess children’s recognition of dynamic events, with motion either adhering to physical laws or contravening them, by placing particular emphasis on the role that object mass plays in such events.

2. Method

2.1 Participants

Participants were recruited from a state primary school located in a suburban area of Cambridge, UK. The sample was drawn from those children whose parents did not object to their participation, and who, when they were non-native speakers of English, were identified by class teachers as capable of understanding the research instructions. This amounted to 121 children (66 girls), including 23 Year 1 children (12 girls; age *M* = 6.15 years, *SD* = 0.40), 31 Year 2 children (18 girls; age *M* = 7.12 years, *SD* = 0.34), 33 Year 4 children (19 girls; age *M* = 9.12 years, *SD* = 0.37) and 34 Year 6 children (17 girls; age *M* = 11.17 years, *SD* = 0.44). An additional nine children participated but were not considered for data analysis due to insufficient completion of practice trials, not completing both tasks, or due to technical errors.

2.2 Design and Materials

Both tasks were computer-presented scenarios involving two balls, a dark green marble and a bright pink table tennis ball (green = ‘heavy’, 75 g, 4 cm diameter; pink = ‘light’, 3 g, 4 cm diameter). Real equivalents of the two balls were made available to the children during the tasks to support full understanding of scenarios, as simulations are more effective in meaning when accompanied by relevant tactile experiences (cf. Lazonder & Ehrenhard, 2014). Scenarios for both tasks were presented using DMDX, which also records response times (Forster & Forster, 2003). The order of scenarios within individual test stages was randomly varied via the computer program.

2.2.1 Prediction task

Scenarios were developed in PowerPoint. Each scenario showed the two balls at their initial point of anticipated motion and being held by a hand. Next to the scenarios were three brief possible motion outcomes written in large font against coloured backgrounds. The options read 'A is faster', 'B is faster' and 'Same speed' (see Figure 1, left). Each of the three response options had a different background colour; the top response had a red background, the response in the middle had a yellow background, and the bottom response had a blue background. Background colours always remained in the same order but response options were rotated across locations. Thus, a total of six scenarios were prepared for this task, amounting to all possible combinations of ball location and response location. In addition, practice scenarios were developed in PowerPoint, with each scenario showing two squares of same or differing sizes with three options to choose from ('A is bigger', 'B is bigger', 'Same size').

2.2.2 Recognition task

Scenarios were recorded with a Sony DCR-HC35E digital video camera recorder. Clips were initially filmed individually with one ball only, using the same set-up of transparent tube placed in a vertical position as in the prediction task. A hand would hold one of the two balls into the tube and release it. Clips were filmed to account for the two ball types and hand location (left versus right). Using Windows Movie Maker each of the clips was slowed down to half the speed. These clips were then compiled to show two tubes within one scenario, ensuring the two balls were always contrasting in colour but accounting for location (left versus right). Both balls were shown being held into the tubes and then released simultaneously (see Figure 1, right). By compiling these clips three different scenarios were created: either showing motion as it occurs naturally ('same-speed'), or showing modified motion where, non-naturally, one ball was twice as fast as the other – either the heavy ball ('heavy-faster') or the light ball ('light-faster'). Thus, a total of six scenarios were prepared for this study, amounting to all possible combinations of ball speed and ball location. Quality of scenarios was not compromised between compilations, including where slowed-down clips had been used. All compiled video clips were 10 s long, with motion occurring at 5 s into the clip, to give enough opportunity to note ball locations. In addition, practice scenarios were developed in PowerPoint, with each scenario either showing a blue circle or a red triangle.

[Insert figure 1 about here]

2.3 Procedure

Each child was assessed on an individual basis. To begin, the child was introduced to the two balls. Both balls could be handled at any time, but the child was prevented from carrying out relevant actions during the task, that is, deliberately letting them fall was not permitted. The trials were presented on a Sony VAIO VGN-NR21J laptop and displayed on an external 15" LCD colour monitor connected to the laptop. An external KeySonic™ Nano

Keyboard ACK-3400U, also connected to the laptop, was used for responding to the trials. The keyboard was masked to reduce distractions from unnecessary keys. Three keys were indicated by colour on the masking. Keys not used were disabled. One key was in the centre of the keyboard (yellow key); the other two were at the left end (red key) and at the right end (blue key) in the same row as the centre key. Each child completed both tasks and the tasks were carried out approximately six weeks apart from one another.

2.3.1 Prediction task

With the monitor screen blank, the researcher familiarised the child with the monitor and the keyboard. He asked the child to point out each key according to its colour. The child was then asked to press the yellow key. This elicited an on-screen introduction to the materials. The child saw a series of diagrams of the monitor and keyboard, which the researcher used to explain the procedure by showing the link between response choices and keys to press. At the end of the introduction the child was told that there would be some easy trials to practice with. If children were unable to read the response options the researcher followed the trials and gave the child instructions, which always corresponded to the particular trial on the screen. Responses were always read out from top to bottom. The researcher pointed to the picture in question and the corresponding response option each time. In the practice trials the researcher would say to the child: "If you think the square on the top [*researcher points at picture A*] is bigger, press the red key. If you think the square on the bottom [*researcher points at picture B*] is bigger, press the yellow key. If you think they are both the same size, press the blue key". For the test trials the child was given the following instruction: "If you think the ball on the left [*researcher points at picture A*] will fall faster, press the red key. If you think the ball on the right [*researcher points at picture B*] will fall faster, press the yellow key. If you think they will both fall as fast as each other, press the blue key". No motion occurred and children were not provided with feedback whether their response was correct or not. Each child was expected to respond to all trials, and the task took around 15 minutes per child.

2.3.2 Recognition task

For half of the children the 'yes' response was the left key and the 'no' response the right key, and vice versa for the other half. For the practice trials, the child was given the following instruction: "Watch carefully, and decide as quickly as you can. I want you to look for a blue circle. Every time you see a blue circle, press 'yes' [*researcher points to 'yes' key*]. Every time you see a red triangle, press 'no' [*researcher points to 'no' key*]". The child was then asked to press the yellow key, which started the trials. For the test trials the child was given the following instruction: "You are going to see two hands holding these two balls [*researcher points to both balls*] inside the tube and letting them go. Watch carefully, and decide, as quickly as you can, whether it looks right or not. If it looks right, press 'yes' [*researcher points to 'yes' key*] and if it does not look right, press 'no' [*researcher points to 'no' key*]". To support the explanation children were shown two sheets of paper next to the two keys, showing the word 'yes' accompanied by a green tick and the word 'no' accompanied by a red cross. Children were not provided with feedback whether their response was correct or not. Each child was expected to respond to all trials, and the task took around 15 minutes per child.

3. Results

Mean scores for both tasks were converted to percentages and analysed according to which types of trials – heavy-faster, light-faster or same-speed – were more likely to be predicted and more likely to be recognised as being correct, regardless of whether they were actually correct. One-sample *t*-tests were used to compare trial type percentages with chance levels (33.3% for each prediction trial and 50% for each recognition trial). One-way ANOVAs and post hoc *t*-tests with Bonferroni corrections were then used to examine differences between the three types of trials in each task type as well as to examine differences between age groups on each trial type. The results are summarised in Figure 2. To examine any further details in the reasoning process of the recognition task one-way ANOVAs and *t*-tests were used to evaluate response times. In addition, between-samples *t*-tests were carried out to evaluate any gender differences. No significant gender differences were noted so these are not considered further. All data were analysed using SPSS 21.

[Insert figure 2 about here]

3.1 Prediction task

Heavy-faster predictions (M = 88.29%, SD = 30.78) occurred significantly more frequently than if performing at chance level, $t(120) = 19.64$, $p < .001$, $r = .87$, with the same effect noted for each age group. There was significant variation in predictions among the four age groups, $F(3, 117) = 3.28$, $p < .05$, but there was only a significant difference between Year 2 and Year 6 children, $p < .017$. Light-faster predictions (M = 6.34%, SD = 23.60) occurred significantly less frequently than if performing at chance level, $t(120) = -12.59$, $p < .001$, $r = .75$, with the same effect noted for each age group. There was no significant variation among the four age groups. Same-speed predictions (M = 5.37%, SD = 20.89) also occurred significantly less frequently than if performing at chance level, $t(120) = -14.73$, $p < .001$, $r = .80$, with the same effect noted for each age group. Again there was no significant age-related variation. Overall, the heavy ball was predicted to be faster more frequently than the light ball, $t(120) = 17.78$, $p < .001$, $r = .85$, but there was no significant difference between light-faster and same-speed predictions.

3.2 Recognition task

Recognition of heavy-faster trajectories as being correct ($M = 44.63\%$, $SD = 39.69$) did not deviate significantly from performance at chance level. Recognition of light-faster trajectories as being correct ($M = 4.96\%$, $SD = 16.34$) was significantly below chance level, $t(120) = -30.33$, $p < .001$, $r = .94$. Recognition of same-speed trajectories as being correct ($M = 79.75\%$, SD = 35.70) was significantly above chance level, $t(120) = 9.17$, $p < .001$, $r = .64$. The same trajectory-related effects were noted within each age group, but there were no significant age-related variations. Overall, same-speed trials were recognised as being correct more frequently than the incorrect heavy-faster trajectories, $t(120) = -5.59$, $p < .001$, $r = .45$. The incorrect heavy-faster trajectories in turn were recognised as being correct more frequently than the equally incorrect light-faster trajectories, $t(120) = 10.09$, $p < .001$, $r = .68$.

Although recognition scores did not vary with age with increasing age children made faster responses. This was the case for heavy-faster trials, $F(3, 117) = 13.37$, $p < .001$, light-faster trials, $F(3, 117) = 11.28$, $p < .001$, and same-speed trials, $F(3, 117) = 11.68$, $p < .001$. Mean heavy-faster trial response times ($M = 3765$ ms, $SD = 1332$) were significantly higher than for light-faster trials ($M = 2243$ ms, $SD = 1114$), $t(120) = 29.52$, $p < .001$, $r = .94$, but mean response times for light-faster and same-speed trials ($M = 2303$ ms, $SD = 1134$) did not differ significantly. The heavy-faster trials were then examined in more detail by comparing response times when both trials were rejected, one was accepted as correct or both were accepted as correct. Mean two-trial rejection times (M = 2996 ms, SD = 1337) were significantly lower than mean one-trial acceptance times (M = 3956 ms, SD = 1233), $t(87) = -3.52$, $p < .05$, $r = .35$, which in turn were significantly lower than mean two-trial acceptance times (M = 4584 ms, SD = 788), $t(74) = -2.53$, $p < .05$, $r = .28$.

4. Discussion

This study was an attempt to evaluate children's predictions and recognition of dynamic events, with particular reference to the role played by object mass. The study sought to answer several questions related to this issue. Firstly, are the widely held limitations observed in children's explicitly stated predictions an accurate expression of their overall understanding about motion? Leading on from this, can children appropriately recognise physically correct and physically incorrect dynamic events on the basis of object mass? If so, how does their recognition of such events compare with their predictive beliefs? And finally, what is the relational manifestation of the different knowledge levels?

As far as the prediction task is concerned, children consistently believed that the heavy ball would be faster than the light ball. These predictions show no significant variation across the age groups and reflect the literature addressing children's beliefs about object fall (Baker et al., 2009; Chinn & Malhotra, 2002; Hast & Howe, 2012, 2013a; Nachtigall, 1982; Sequeira & Leite, 1991; van Hise, 1988). At the same time, despite holding predictive conceptions incommensurate with real events it is clear from the present results that the same children are able to correctly recognise object motion. Accuracy is revealed in their ability to accept physically natural events as correct and to reject non-natural events. This general finding is in line with prior literature on underlying recognition (Friedman, 2002; Howe et al., 2012, 2014;

Kaiser & Proffitt, 1984; Kaiser et al., 1992; Kannass et al., 1999; Kim & Spelke, 1992, 1999; Naimi, 2011; Shanon, 1976), particularly with those of the studies that are concerned with children. More specifically, however, the findings suggest that children can correctly recognise dynamic events despite the central role object mass plays in the development of predictive beliefs about motion. Their predictions are considered to be explicit conceptual knowledge since identical responses were obtained in tasks requiring children to give verbal justifications for their predictions using the same apparatus (Hast & Howe, 2013a) and showing high similarity between real-life object tasks and computer-presented versions (see Hast & Howe, 2013b).

Nonetheless, the role of object mass does not appear to be entirely irrelevant in recognition of events. Children consistently acknowledged the correctness of trials where the balls travelled at same speeds. At the same time, they almost always rejected light-faster trials – trials that are neither physically correct nor reflected in their predictions. No significant changes with age were noted, suggesting some stability in recognition of motion across childhood. Trials corresponding to explicit predictions, on the other hand, were recognised as correct rather frequently: Children fairly often recognised incorrect trials to be correct where the heavy ball was faster. This may be linked to deliberation. Underlying knowledge is typically associated with fast evaluation whereas explicit knowledge is accessed through prolonged evaluation (Collins, 2010). More careful reflection on scenarios may have provided access to explicit knowledge structures. Research with young children may provide similar supportive insight. Upon following falling events 2-year-olds initially looked at the correct location but then largely pointed at an incorrect location (Lee & Kuhlmeier, 2013). Here, too, children may initially have held underlying expectations that were correct but prolonged deliberation resulted in misconception. This also seems to be exemplified by the response time data, although more careful examination in task variations would help shed more light on this matter, such as through time constraints and the impact on recognition accuracy. Despite this issue, as a whole the children were still much better at recognising true dynamic events but simply refined their ability to do so with increasing age.

Failure in various search tasks is denoted by toddlers reaching for incorrect locations, especially when multiple incorrect locations are provided – but looking behaviour data in these same studies indicate that they are aware of the correct location (e.g. Baker, Gjersoe, Sibielska-Woch, Leslie, & Hood, 2011; Haddad, Kloos, & Keen, 2008; Hood, Cole-Davies, & Dias, 2003). Indeed, recent work addressing conceptual knowledge in a range of domains has identified that although scientific knowledge can be learnt it does not appear to replace earlier understanding about those concepts (Shtulman & Valcarcel, 2012). It is plausible that additional task requirements, in this case processing of language when choosing response options, interfere with retrieval of underlying information (cf. Low, 2010). Parallels can thus be drawn to Karmiloff-Smith's (1992) discussion that mastery of a particular executive skill level is required before a new skill level can be engaged with. This would also explain why children did not differ across age groups in their actual recognition scores but did improve by becoming faster at reaching the same level of decisions. As this study only focused on middle childhood it is possible that further refinement either in terms of accuracy or in terms of response speed would be noted towards adulthood (cf. Naimi, 2011) that could help explore a more complete developmental trajectory. However, because different task types require skills of different difficulty level (e.g. looking, reaching or verbal responses) each mode is represented at the same time but only the most relevant information is actively retrieved. The work by Shtulman and Valcarcel, and other work showing, for instance, Alzheimer's patients reverting to childhood conceptions (Lombrozo, Kelemen, & Zaitchik, 2007), would appear to support this notion.

But are these layers a single representation of knowledge, independent from one another, or overlapping? Out of the three potential views offered in the literature, omission (Kim, 2012; Kim & Spelke, 1999; Spelke & Hespos, 2001) would appear to be the least likely candidate. For if the disparity observed in the present study were due to omission, then deliberation should call upon underlying knowledge and leave out conceptual elements. But since object mass actually plays a very minor role in natural object motion events, same-speed recognition would not necessarily depend on any understanding of mass in order to correctly identify trials, and children are evidently satisfactorily adept in their recognition of events. Yet they specifically call upon mass in order to support their – mostly erroneous – predictions. It therefore seems more likely that predictive beliefs during childhood are either the result of an independently developed knowledge system or that they are an embellished form of tacit understanding, whereby additional information about object mass is added to the underlying knowledge structures. This means the hypothesis R = H>L=S cannot be accepted here.

Distinguishing further between separate systems (Hogarth, 2001; Plessner & Czenna, 2008) and the hybrid model (Carey, 2009; Howe, 2014; Howe et al., 2012, 2014), on the other hand, is a more formidable task. Nonetheless, the results from the present study seem to favour the hybrid model, since here too the substantial instances of recognition that mirror predictive knowledge suggest overlap between the two knowledge systems in a way that was anticipated by the hypothesis R = S>H>L. Instead it is suggested that access to relevant conceptual structures is affected by various factors such as language and executive control and is therefore dependent on task requirements – looking, manual or verbal – that determine the depth of conceptual layers that needs to be overcome. In a simple recognition task children may merely need to map dynamic events onto relevant pre-existing models and rejection or acceptance is based on the goodness of fit with these models. Explicit predictions require input from some form of symbolic representation such as language or symbols which may add onto the underlying knowledge, such as through discourse (an explanatory dual-pathway model of reasoning is presented in Hast, 2014). This is equally compatible with the dual processing pathways used to explain differences between infants and toddlers (e.g. Gjersoe & Hood, 2009) but favours the view that they are not separable from one another.

5. Conclusion

Children's knowledge about the physical world is extensive but often expressed in a manner incommensurate with scientific views. At the same time a popular viewpoint is that we hold underlying knowledge about physical events that, at its core, remains unaltered throughout development, but with further knowledge added to it. The present study shows that while children's predictions are inaccurate their recognition of related dynamic events is largely correct. However, instead of omitting information at the predictive level it appears children are adding mass as a key variable. Such additional conceptual layers may hinder access to underlying knowledge, depending on task requirements, but underlying knowledge may nonetheless still be tapped through recognition tasks and access may become easier with increasing age.

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