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Adults' Understanding and 6-To-7-Month-Old Infants' Perception of Size and Mass Relationships in Collision Events

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Abstract: Humans first start to perceive the relationship between object size and mass in simple collision events at about 5.5–6.5 months of age. They perceive this link in simple collision events by attending to the size of the moving object and anticipating a greater displacement after collision with a large object and a lesser displacement with a small object. The results this aforementioned experiment is based on infants' responses to a large and small object propelling a stationary object to the same distance (long distance). It is unknown how infants would perceive the same events if a large and small object propelled a stationary object to size appropriate (congruent) and size inappropriate (incongruent) distances. This paper aims to investigate this with adults (experiment 1) and 6-to-7-month-old infants (experiment 2). The first experiment served to validate our computer-generated collision events, by asking adults (N = 24) to rate the likeness of collision events happening in real-life, based on object size. In the second experiment, we tested this phenomenon in infants (N = 16) using the looking time paradigm. Results from the first experiment revealed that our computer-generated collision events are in line with adults' assumptions of size-appropriate and size-inappropriate distances that the cube is propelled to by the small and large ball. Adults rated congruent test events as more likely than incongruent test events when asked how real-life-based they were. Results from the second experiment revealed infants distinguished between the sizes by preferring to look at the large ball longer than the small ball. However, the infants did not differ in their looking times for congruent and incongruent test events for small or/and large balls. For that reason, we conclude infants can distinguish between the sizes of the balls but are unable to perceive the size and mass associations in collision events.

Keywords: looking time; collision events; violation of expectation; object size; infants; baby physics

1. Introduction

Principles of physical causality are claimed to be present very shortly after birth [1]. Babies of 8 h to 71 h of age display a preference for a computer animated physical causal event (one object hitting another object and causing it to move) over a delayed launching event (one object hitting another object and causing it to move after a short delay) or non-causal event (one object hitting another object and the order of the two objects swap location [1]. At the age of 2.5 months, infants start to expect that a stationary object will move after a collision with a moving object, but not after a delay between the collision of the two objects [2]. The expectations of object properties and outcomes involved in causal events only happen at a later age [3].

Infants make size and distance inferences in collision events at around 5.5 to 6.5 months of age [3]. Infants attend to the size of objects and anticipate a certain momentum outcome

depending on the size of the object [3]. For example, infants of 5.5 to 6.5 months of age expect larger objects to propel a stationary object to a further distance than a smaller object in collision events [3]. These findings were demonstrated in the study by Kotovsky and Baillargeon [3] by infants' greater looking time at the event in which a small cylinder propelled a colourful toy bug to the endpoint of the screen compared to the event in which a large cylinder propelled it to the endpoint of the screen. However, these findings only prevailed if infants were previously habituated to an event in which the mid-size cylinder propelled the colourful toy bug to the midpoint of the screen [3]. Infants that were first habituated to an event in which the mid-size cylinder propelled the toy bug to the endpoint of the screen did not demonstrate any differences in looking time behaviour towards the small and large cylinder [3].

Similar results were obtained with computer-animated collision events at around 10 months of age [4]. These computer-animated collision events differ from the original experiment by Kotovsky and Baillargeon [3] in regard to the motion of the objects. In the original experiment [3], the billiard balls were put on a ramp by a hand, and then the hand released the ball so that it rolled down the ramp and hit the colourful toy bug. However, in the experiment by Hohenberger and colleagues [4], the balls appeared on the top of the ramp and then rolled down from the ramp without any manipulation by a hand. Under these conditions, the study by Hohenberger et al. [4] did not produce similar results with 6-month-old infants but did so with 10-month-old infants. Regardless of this, both these studies demonstrate that infants consider object size in collision events and anticipate certain outcomes of the stationary object depending on the size of the moving object [3,4].

It is well-established that size cues for mass with the principle that larger objects are perceived to be heavier in weight than smaller objects [5]. As evidenced by the studies from Kotovsky and Baillargeon [3] and Hohenberger et al. [4], larger objects (greater in mass) are expected to make a stationary object propel further than a smaller object (less in mass). Mass cues aid the expectation, learning, and understanding of object interactions [6]. Given that infants base their inferences about object behaviour and interaction on size, which is an indirect measure of mass in collision events, there is a need to examine object properties that cue mass in infants [3,4].

There is some evidence that suggests infants are successful in discriminating between object weight haptically [6,7]. Infants learn to discriminate object weight early on in their lives, and when newborns, they acquire skills to haptically discriminate object weights [7]. This is demonstrated by changes in neonates holding times, exerted pressure, and frequency of exerted pressure across light and heavy objects [7]. Not only do they display this skill in light rooms with the aid of visual cues but also in a dark environment at 3 months of age [6]. However, infants' ability to visually discriminate between object properties and their relative masses has not been demonstrated in any other studies apart from the aforementioned studies [3,4]. As a result of this scarcity of research, the two experiments presented herein examined adults' (experiment 1) and 6-to-7-month-old infants' (experiment 2) visual discrimination between object masses based on object size in the context of collision events. Experiment 1 was conducted on adults, and in addition to addressing the scarcity of research previously mentioned, also served as a precursor for experiment 2 with 6-to-7-month-old infants. The experiments followed a computer-generated approach with a child-friendly design [3,4,8]. In this context, adults and 6-to-7-month-old infants were presented with two different collision outcomes for each object size (large or small); a shorter and longer travelled distance of stationary object after collision with an object. In a collision event between object A (agent) and object B (patient), we tested whether the object size of object A (large or small) would affect adults' and children's perceived exerted force on object B. We hypothesised that a priori collision event outcomes aligned with cued mass of object A (congruent test events) would be rated higher by adults than collision event outcomes that did not align (incongruent test events). Adults rated events on a Likert scale based on how real-life they were from 1 (very unlikely) to 10 (very likely). Furthermore, we hypothesised that infants would display a longer looking time at collision event outcomes

that did not align with the cued mass of object A (incongruent test events) than collision event outcomes that did (congruent test events).

2. Experiment 1 Methods

2.1. Participants

A total of 24 adult participants between the ages of 23 years and 36 years (aged 27.46 ± 4.25 years) took part in the study to validate the experiment prior to use with infants. All participants were recruited from Lancaster University. Participants had normal or corrected-to-normal eyesight and received refreshments for their participation. Of these 24 participants, 12 were females (aged 26.00 ± 4.03 years) and 12 were males (aged 28.42 ± 4.42 years).

2.2. Materials and Apparatus

Computer-generated collision events were created using Animate C.C (2016), Adobe Systems. Participants watched dynamic collision events on a screen. The backdrop consisted of an image of a wooden table (W = 20.89 cm, H = 5.07 cm), background of three houses (W = 13.81 cm, H = 5.50 cm), a ramp (W = 3.92 cm, H = 2.51 cm), a cube (W = 2.51 cm, H = 2.51 cm), a hand (W = 2.51 cm, H = 2.01 cm), a small ball (H = 1.06 cm, W = 1.06 cm), medium ball (H = 1.59 cm, W = 1.59 cm), and large ball (W = 2.38 cm, H = 2.38 cm).

Adults saw the habituation event before the test events; in this event, the cube was propelled by a ball to the midpoint position (habituation distance). In the test events, adults saw the cube propelled by a ball to a position either before the midpoint (shorter distance) or at the endpoint (longer distance) of the screen. In the habituation event, the cube was propelled by a ball of physical properties cuing mid-mass (mid-size ball) to one distance (midpoint). In the test events, the cube was either propelled by a ball of physical properties cuing greater mass (large ball) or lesser mass (small ball). Test events showed a large ball or small ball propel the grey cube to a size-appropriate distance (congruent) and a size-inappropriate distance (incongruent). In the congruent outcomes, the small ball propelled the cube to before the midpoint, and the large ball propelled the cube to the endpoint of the screen. In the incongruent outcomes, the small ball propelled the cube to the endpoint and the large ball propelled the cube to before the midpoint.

Participants were shown test event scenes in which a hand was presented but the ball was hidden (for 1 s). Subsequently, the hand was hidden and then visible again holding the ball (for 1 s). The hand placed the ball on the ramp, pressed it down, and after 1 s, the hand was lifted. The ball rolled down the ramp (for 1 s) and propelled the cube in front of the first house to either the end of the first house or midpoint or to the last house (for 1–2 s). These events continued 1 s after the movement ended to allow participants time to perceive the event in its entirety. In total, events in which the cube propelled to the end of the first house or midpoint lasted 6 s (240 frames, 48 frames/s), and events in which the cube propelled to the last house lasted 7 s (288 frames, 48 frames/s). The cube travelled 1.5 cm/s from the start of the first house to the end of the first house (shorter condition) or to the midpoint (midpoint condition). The cube travelled 1.17 cm/s from the start of the first house to the middle of the third house (longer condition).

The auditory stimulus that was presented during the collision was a natural sound of a billiard ball hitting a wooden cube. Audition C.C. (2016), Adobe Systems was used to amplify the sound. This stimulus was used for all test events for all experiments. The stimulus had a duration of 0.3 s, an acoustic amplitude of 50–58 dB (range), and an auditory frequency of 32–851 Hz (range). The impact sound (i.e., when the ball hit the cube) was 851 Hz and 58 dB.

2.3. Procedure

Adults were randomly assigned to one of four groups (N = 6 per group) according to the order in which events were watched:

Group one: B-C-E-D

Group two: E-D-B-C
Group three: C-B-D-E
Group four: D-E-C-B

Irrespective of the group, adults first watched a habituation event where a mid-size ball displaced a cube to the midpoint of the screen (event A in Figure 1). This habituation event was rated as 4.79 ± 2.28 (arbitrary units) in terms of likeliness. Adults watched events on a Macbook Air 33.78 cm screen with headphones on, and verbally assessed the collision events by rating them on a scale from 1 (very unlikely) to 10 (very likely) on how real-life they were.
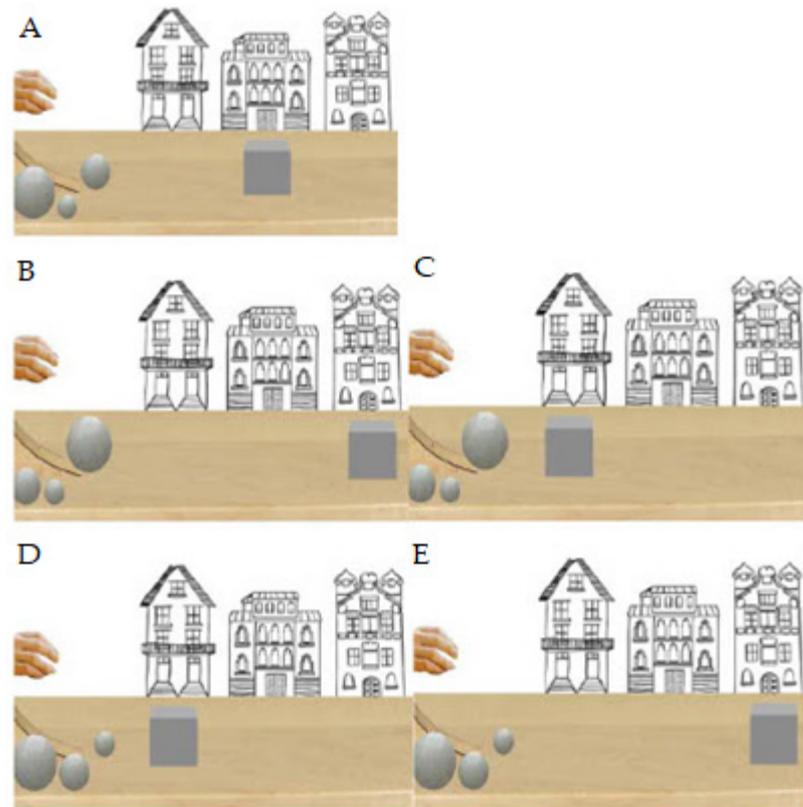
Figure 1. (**A**) Habituation event, (**B**) Large ball congruent, (**C**) Large ball incongruent, Bottom: (**D**) Small ball congruent, (**E**) Small ball incongruent event outcomes.

3. Experiment 1 Results

All data were analysed using SPSS version 21 (IBM North America, New York, NY, USA). Data were tested for normal distribution by Shapiro-Wilk's test and for homogeneity of variance using Levene's test. Following confirmation of parametricity, an analysis of variance (ANOVA) with repeated measures was used to test for differences in rating, with order group (1, 2, 3, or 4) and sex (male or female) as a between-subjects factor, and size (large or small) and congruency (congruent or incongruent) as within-subjects factors. Subsequently, post hoc paired samples t-tests with Bonferroni corrections were performed to locate differences. We report alpha levels as exact P values, without dichotomous interpretation of 'significant' or 'non-significant' as advised by the American Statistical Association [9]. Effect sizes are reported using partial eta squared (ηp^2) for ANOVA and Cohen's *d* (difference in means $\div$ pooled standard deviation [SD]) for pairwise comparison. ηp^2 was interpreted as small (0.02), medium (0.13), and large (0.26) effects. Cohen's *d* was interpreted as small (0.2), medium (0.5), and large (0.8) effects [10]. Figures were generated in GraphPad Prism (GraphPad Prism 8.4.3, GraphPad Software Inc., San Diego, CA, USA) and the display grouped dot plots with mean and 95% confidence intervals (CIs)

as recommended by Drummond and Vowler [11] and Weissgerber et al. [12]. Data are presented in the text as mean $\pm$ SD.

Test trials

The main effect of size from the ANOVA was (F (1, 16) = 12.40, $p < 0.01$), np^2 = 0.44. The main effect of congruency from the ANOVA was (F (1, 16) = 8.31, $p = 0.01$, np^2 = 0.34), with adults rating the congruent test events (7.10 $\pm$ 2.55) more likely compared to incongruent test events (2.68 $\pm$ 2.40). The interaction effect between size and congruency from the ANOVA was (F (1, 16) = 24.69, $p < 0.001$, np^2 = 0.61). Adults rated the small congruent event (6.71 $\pm$ 2.52) more likely than the small ball incongruent event (2.26 $\pm$ 2.36; $p < 0.001$: d = 1.82; Figure 2). Furthermore, adults rated the large congruent event (7.54 $\pm$ 2.59) more likely than the large incongruent event (3.08 $\pm$ 2.77; $p < 0.001$: d = 1.66; Figure 2). There was no effect of order group (F (3, 16) = 1.12, $p = 0.37$, np^2 = 0.25) nor sex (F (1, 16) = 0.78, $p = 0.39$, np^2 < 0.10).
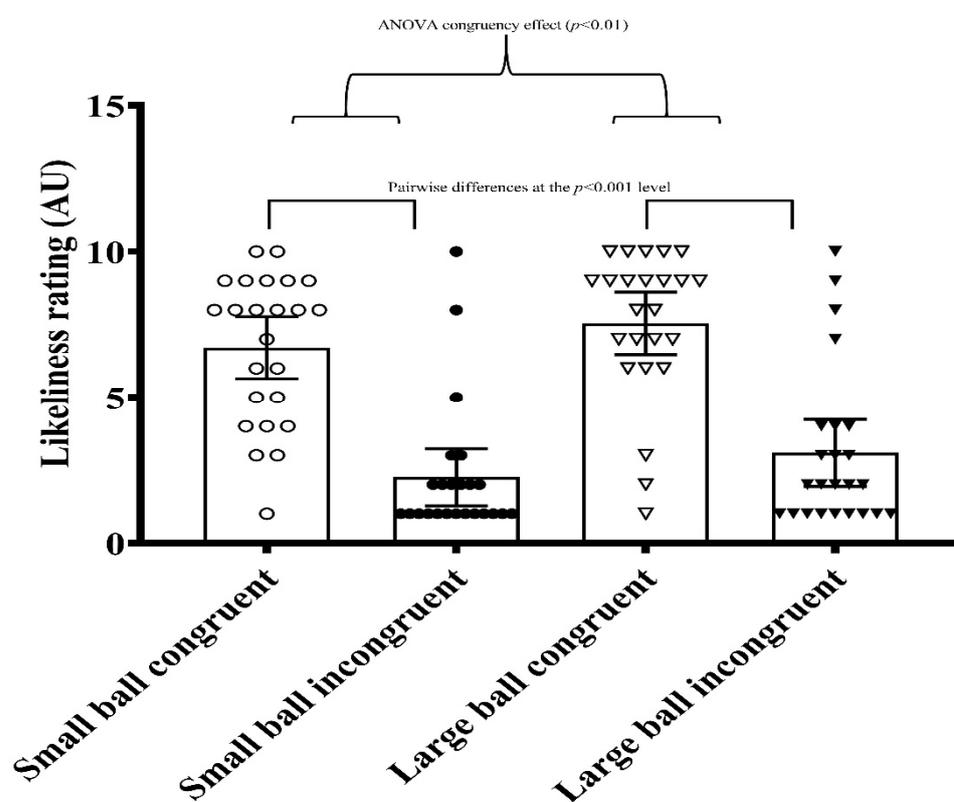
Figure 2. Mean ratings of small and large ball congruent and incongruent test events. Data are presented as grouped dot plots and mean and 95% confidence intervals. AU = arbitrary units.

4. Experiment 2 Methods

4.1. Participants

A total of 56 infant participants took part in the study, but due to equipment failure (N = 5), fussiness (N = 3), failure to habituate (N = 17), and successful habituation but failure to watch test events (N = 15), the final sample consisted of 16 participants. Infants that failed to habituate did not display a decreased responsiveness to repeated stimuli. Furthermore, infants that successfully habituated but failed to watch the test events displayed a looking time duration that was shorter than the duration of the collision event taking place; this meant the infant did not see the full collision event. The 16 participants were aged between 181 days and 210 days (aged 195 $\pm$ 11 days). Participants were recruited from the database at Lancaster University Babylab. Participants were healthy, full-term infants and received a book for their participation alongside being reimbursed for travel costs. Of these 16 infants, 8 were female (aged 193.25 $\pm$ 8.94 days) and 8 were male (aged 196.63 $\pm$ 12.74 days).

4.2. Materials and Apparatus

Animations were the same as in Experiment 1, except that the habituation event was shown in a loop of nine trials until test events were shown. Habit 2000 software (Cohen, & Chaput, 2000) was used to time presentation and to record looking times input by the experimenter. A camera, situated through a small circle on the black card surrounding the screen, was used to record looking behaviour. Each session was recorded so the data could be re-coded by a second observer.

4.3. Procedure

Following parental consent to take part in the experiment after being informed about the study, infants were subdivided (M = 2, F = 2) into four groups (N = 4) to counterbalance the order of the test events. Infants viewed the computer-generated collision events in the specific order outlined for experiment 1.

Infants first viewed the habituation trials. The habituation trials were viewed till successful habituation or completion of all nine trials. One habituation trial was presented in a loop for a maximum of 60 s. The duration of the habituation trial was infant-dependent. A rattle was presented after the end of each habituation trial to direct infants' attention back to the screen. Next, infants were presented with the four test trials in that specific order depending on the group they were assigned to. Infants saw the test trials in a loop for a maximum of 60 s. The duration of the test trials was again infant-dependent. A rattle was presented after the end of each test trial to direct infants' attention back to the screen.

5. Experiment 2 Results

The same statistical analysis was adopted as for Experiment 1.

Habituation trials

The looking time data for both habituation and test trials were not normally distributed thus a log transformation was performed. Infants' looking time during the last four habituation trials were analysed with a 4 × 4 mixed-model analysis of variance (ANOVA) with order group (1, 2, 3, or 4) as a between-subjects factor and habituation trials (1–4) as a within-subject factor. The analysis revealed a significant main effect of habituation, ($F_{(3, 36)} = 18.10$, $p < 0.001$, $np^2 = 0.60$) demonstrating a difference in looking time across habituation trials. There was no effect of order group ($F_{(3, 12)} = 0.53$, $p = 0.67$, $np^2 = 0.12$), meaning that looking time across order groups did not differ. The interaction between order group and habituation was not significant, ($F_{(9, 36)} = 0.71$, $p = 0.71$ $np^2 = 0.70$). This means that infants in the different order groups did not differ in their looking times across habituation trials.

Test trials

The main effect of congruency from the ANOVA was ($F_{(1, 8)} = 2.22$, $p = 0.17$, $np^2 = 0.22$). The main effect of size from the ANOVA was ($F_{(1, 8)} = 18.55$, $p < 0.01$, $np^2 = 0.70$), in the direction of longer looking time at large ball test events (M = 1.10 ± 0.26) in comparison to small ball test events (M = 0.95 ± 0.2; $p < 0.001$; $d = 0.65$; Figure 3). The interaction between size and congruency from the ANOVA was, ($F_{(1, 8)} = 0.83$, $p = 0.39$, $np^2 < 0.10$; Figure 3). There was no effect of order group ($F_{(3, 8)} = 0.54$, $p = 0.67$, $np^2 = 0.17$) nor sex ($F_{(1, 8)} = 0.66$, $p = 0.44$, $np^2 \leq 0.10$).
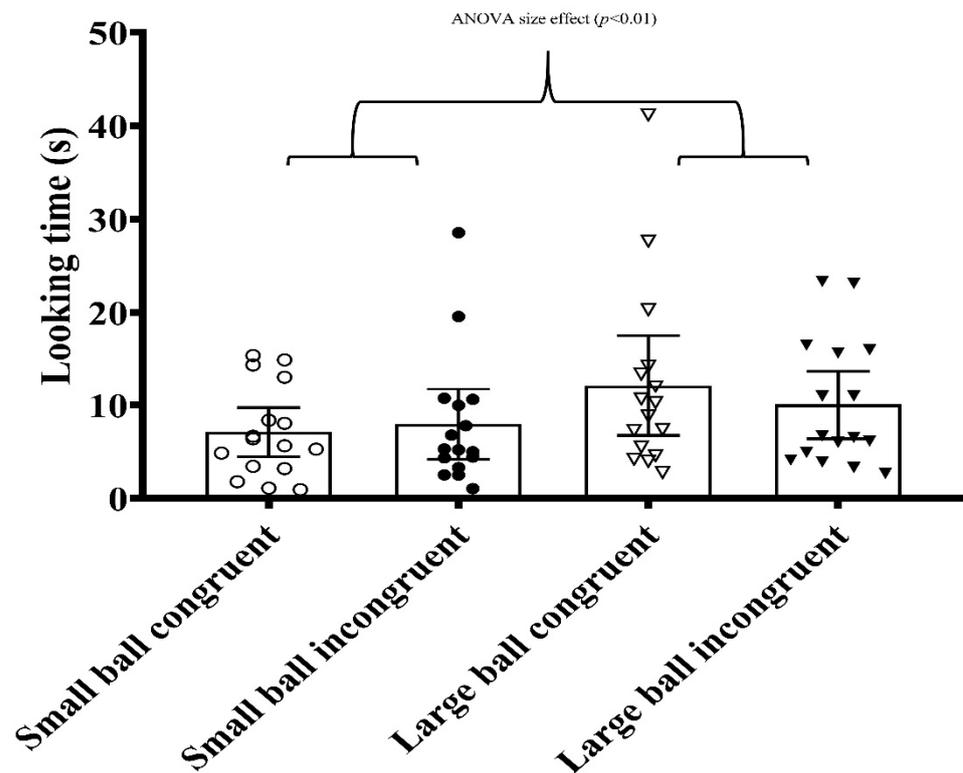
Figure 3. Looking time for small and large ball congruent and incongruent test events. Data are presented as grouped dot plots and mean and 95% confidence intervals. AU = arbitrary units.

6. General Discussion of Findings

Experiment 1 summary of findings

Results from experiment 1 suggest adults rated congruent test events more likely than incongruent test events. These findings suggest that our computer-generated collision events are in line with adults' assumptions of size-appropriate and size-inappropriate distances the cube is propelled to by the small and large ball. Furthermore, the size and congruency interaction further supports this. Adults rated the congruent test events for both sizes higher than incongruent test events for both sizes. For that reason, we conclude that our computer-generated collision events are validated by our adult sample.

Experiment 2 summary of findings

Results from experiment 2 suggest infants distinguished between the sizes by preferring to look at the large ball longer than the small ball. Infants did not differ in their looking times for congruent and incongruent test events. Similarly, infants did not differ in their looking times for congruent and incongruent test events for both a small and large size ball. For that reason, we conclude infants can distinguish between the sizes of the balls but are unable to perceive the size and mass associations in collision events.

General discussion of findings

Results from Experiment 1 validate the use of our version of the computer-generated collision events. Rating differences between the congruent and incongruent test events for large and small ball test events suggest that adults think our collision events are in line with their expectations of these physical events happening in real life.

Results obtained from Experiment 2 suggest that 6-to-7-month-old infants are sensitive to size differences across stimuli, indicated by their longer looking time at larger objects irrespective of test conditions (shorter or longer distance the cube is propelled to). The collision events introduced in this paper demonstrated an alternative methodology to Kotovsky and Baillargeon's [3,8] version of collision events to examine infants' expectations

about object size in collision events. The results obtained with the infants within this paper did not produce results in line with Kotovsky and Baillargeon's [3] findings. Previous studies that have investigated size in collision events have found a difference in looking time between the large and small ball events in which the cube is propelled to the endpoint of the screen [3,4]. In these studies, both 5.5–6.5 and 10-month-old infants looked longer at the small ball event compared to the large ball event. This suggests that infants find the small ball event to violate their expectations. In line with these findings, we were expecting similar results regardless of the two extra conditions we introduced in which small and large ball propels the stationary object to a short distance. On the assumption that infants use size to infer mass in collision events as concluded by Kotovsky and Baillargeon [3], infants should be able to discriminate between object sizes in the short distance condition similar to the long distance condition found in the study. Based on this assumption, infants should have looked longer at the event in which a large ball propels a stationary object to a short distance compared to a small ball displaying the same behaviour. Instead, we found infants looked longer at large ball events compared to small ball events, irrespective of distance. Large and tall objects may catch infants' attention for several reasons. Larger objects might signal danger (evolutionary hypothesis) or be more prominent. However, past research suggests that despite infants' gradual move from a preference for larger size to more complex features of objects, object size is still vital in their visual preference during the first 12 months of life [13]. Infants in their first year of life tend to prefer to look at larger objects first compared to smaller objects in a preferential-looking setting [13]. This can be explained by the more prominent details of a larger object [14]. Furthermore, this can explain infants longer looking time to test trials that involved a large ball in Experiment 2.

The experiments of Kotovsky and Baillargeon [3] were conducted with real-life objects as opposed to computer-generated collision events like our experiments [8]. However, Hohenberger et al. [4] were successful with their replication of Kotovsky and Baillargeon [3] study with 10-month-old infants using animation. Hohenberger et al. [4] were successful with 10-month-olds but not 6-month-olds, despite using self-propelled objects. Self-propelled objects were used in their study because the moving object rolled down the ramp on its own without an external force as a hand was not present to set objects in motion [4]. In our experiment, we controlled for this by inserting a picture of a hand that manipulated the objects and set them into motion [8]. Hohenberger and colleagues' [4] successful replication with 10-month-olds but not 6-month-olds suggests that the self-propelled nature of their animations might have been the restricting factor. Several studies suggest that infants behave differently when shown animate objects characterised by their self-propelling nature and inanimate objects (real objects); infants fail to perceive the violation of expectation when viewing animate objects [15–19]. Nevertheless, this suggestion has been challenged in recent years by various authors who have been successful with using animate (self-propelled) objects [1]. Infants as young as 8 h to 71 h have demonstrated a preference for causal events over non-causal with the use of self-propelled objects [1].

Looking time data obtained from our studies demonstrated that infants did not differentiate between incongruent and congruent test trials for object size. This suggests the task might have been ambiguous or complex for an infant audience. There are a number of variables that infants need to consider such as (a) object size of the balls and the cube assessed separately, (b) the properties of the balls and the cube assessed in relation to one another, and (c) the likely force one object with a certain property will exert on another object with a certain property. As such, the variables involved in perceiving the object size and their cues to mass in collision events might require advanced reasoning beyond that of this age range.

In conclusion, experiments in this paper demonstrate that adults perceive and understand the relationship between mass and object size in collision events. Conversely, infants failed to perceive the relationship between mass and object size in collision events. This is concluded from infants' inability to differentiate in looking time between incongruent and congruent test trials. However, infants notice size differences and mass differences

across stimuli. Future research could benefit from replicating the experiment herein but with older infants or children. We suggest this as in experiment 1, adults understood the relationship between mass and object size in collision events, so it would be of interest to determine at what age this understanding and perception becomes manifest.

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Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data will be made freely available on request.

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