Mass Perception of Objects in Collision Events from a Developmental Perspective

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To my Family

“*It is with children that we have the best chance of studying the development of logical knowledge, mathematical knowledge, physical knowledge, and so forth*”

-Jean Piaget

Declaration

This thesis has not been submitted in support of an application for another degree at this or any other university. It is the result of my own work and includes nothing that is the outcome of work done in collaboration except where specifically indicated. Some of the ideas in this thesis were the product of discussion with my supervisors Prof. Gavin Bremner and Dr. Peter Walker.

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Abstract

Around 5.5 to 6.5 months of age, humans first start to perceive the relationship between size and mass in simple collision events by attending to the size of the agent object (Kotovsky & Baillargeon, 1998). Infants of this age perceive a greater displacement after collision with a large object and a lesser displacement with a small object. The results are based on infants' looking time responses to a large and small object propelling a patient object to one distance, the endpoint of the screen. It is unknown how infants and adults would perceive the same events if a large and small object propelled a patient object to size appropriate (congruent) and size inappropriate (incongruent) distances. Furthermore, uncertainty remains about how infants and adults perceive object brightness and sound pitch, and their mass cues in collision events. It is documented that adults judge dark coloured objects and lower pitch sounds to be heavier in weight than bright coloured objects and higher pitch sounds (Walker, Francis, & Walker, 2010; Walker, Walker, & Francis, 2012). Similarly, infants around 10 months of age associate low pitch sounds with dark coloured objects, and high pitch sounds with bright coloured objects (Haryu, & Kajikawa, 2012). Moreover, it is unknown at what point in development humans start to perceive and process the differences between size of an agent object and a patient object. Specifically, the perception of the collision between an agent object that is constant in size and a patient object that varies in size. To these means, this thesis presents a series of experiments that examine adults' reasoning and infants' perception of object size of both agent and patient object, object brightness and sound pitch objects emit during collision and their mass cues in the collision events.

Chapter 3 examines adults' reasoning about object size, object brightness and sound pitch objects emit during collision and their cues to mass in three-dimensional computer-generated collision events. Results suggest that adults sometimes base their mass judgements on visual cues

such as object size and object brightness. However, adults fail to consider sound pitch during collision as a cue for mass in the collision events.

Chapter 4 investigates the 6-to-7-month old infants’ perception of object size and object brightness separately and together and their cues to mass in 3D computer-generated collision events. Results in Chapter 4 indicate that these experiments fail to provide evidence that infants perceive mass cues of object properties size, brightness, and size and brightness in collision events.

Chapter 5 concerns the 10-to-11-month old infants’ perception of object size of agent object and patient object and their cues to mass in 3D computer-generated collision events. Results in Chapter 5 indicate that these experiments fail to provide evidence that infants use mass cues of object size of agent and patient object in collision events.

Results of this thesis clarify how adults reason and how infants perceive object size, object brightness and sound pitch and their cues to mass in collision events. Furthermore, this thesis clarify how infants use object size of the agent object and the patient object and their cues to mass in collision events.

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Chapter 1 - General Introduction and Literature Review

1.1 General introduction

Collision events can be designed to examine adults’ physical reasoning and infants’ perception of causal events (Luo, Kaufman, & Baillargeon, 2009; Scholl, & Nayakama, 2002). A simple collision event involves an agent object A and a patient object B. The agent object A hits the patient object B, and causes object B to move. This causal relationship between an object A and an object B is then attributed to knowledge of object properties, object behaviour and interaction (Kotovksy, & Baillargeon, 1994; 1998; Vicovaro, & Burigana, 2014). For example, adults judge a collision between objects of materials such as plasticine (less elastic) to be slower than a collision between objects of materials such as wood (more elastic) based on elasticity of colliding objects (Vicovaro & Burigana, 2016). Furthermore, adults base their judgements of collision events on the sizes of the agent and the patient object (Schiff, & Detwiler, 1979). Adults expect large sizes to exert more force, and therefore to propel an object further in such collision events (Schiff, & Detwiler, 1979). Infants from 5.5 to 6.5 months of age are also known to take account of size in simple collision events by perceiving a greater displacement after a collision with a large object, and a lesser displacement after a collision with a small object (Kotovsky, & Baillargeon, 1998). Moreover, adults consider velocity ratios and mass cues of objects of varying sizes and material properties such as polystyrene, wood and iron in the assessment of natural and unnatural causal collision events (Vicovaro & Burigana, 2014). The collision between sphere A and B is judged to be natural or unnatural based on pre-collision velocity of object A and the post-collision motion of object B that is based on the implied masses of both objects A and B (Vicovaro & Burigana, 2014).

Inferences about how objects of certain properties behave in relation to one another or alone in the collision events cannot happen in isolation of mass estimates of the object (Woodworth, 1921). The momentums in the collision events are a product of mass and velocity (Vicovaro & Burigana, 2014; 2016). In the study of Schiff and Detwiler (1979) mentioned earlier, adults anticipated a large object to propel a patient object further than a small object, because adults expected the large object to have greater mass than the small object. Object sizes in collision events cue for mass (Schiff & Detwiler, 1979). Consequently, objects of greater masses exert more force on other objects and thus displace them further than objects of lower masses (Kotovsky, & Baillargeon, 1994; 1998; Vicovaro, & Burigana, 2014). Similarly, in the study of Vicovaro and Burigana (2014) mentioned earlier, adults judged collisions between objects of different sizes and material properties such as polystyrene, wood and iron to be natural and unnatural based on the pre-collision velocity of the object A and post-collision motion of the object B which is dependent on the masses of both objects A and B. In sum, object properties and their mass cues are important in understanding the outcomes of collision events. Yet, object properties involved in collision events are understudied.

In recent years, object brightness and pitch of sound emitted by objects have been demonstrated to cue weight in adults when objects have been lifted (Walker, 2012a; 2012b). For example, darker coloured objects have been judged to be heavier in weight and light weight objects to elicit high-pitched sounds (Walker, 2012). Similarly, toddlers and 10-month-old infants associate object brightness with pitch sound (Mondloch, & Maurer, 2004; Haryu, & Kajikawa, 2012). For example, both toddlers and infants associate low pitch sounds with darker coloured objects, and high pitch sound with bright coloured objects (Mondloch, & Maurer, 2004; Haryu, & Kajikawa, 2012). However, I am unaware of any research that demonstrates how adults reason and how infants perceive object brightness and pitch sound, and their cues to mass in collision events.

The aim of the research reported in this thesis is to examine adults' reasoning and infants' perception of the collision events based on object brightness and pitch sound, and their cues to mass. In this chapter, an overview of the collision events and humans' perception of object properties and their cues to mass in dynamic events. Subsequently, the literature review will address the topic of humans' perception of objects and their physical properties, and adults'reasoning and infants' perception of these objects in dynamic events.

1.2 Collision events

1.2.1 The perception of causality in collision events

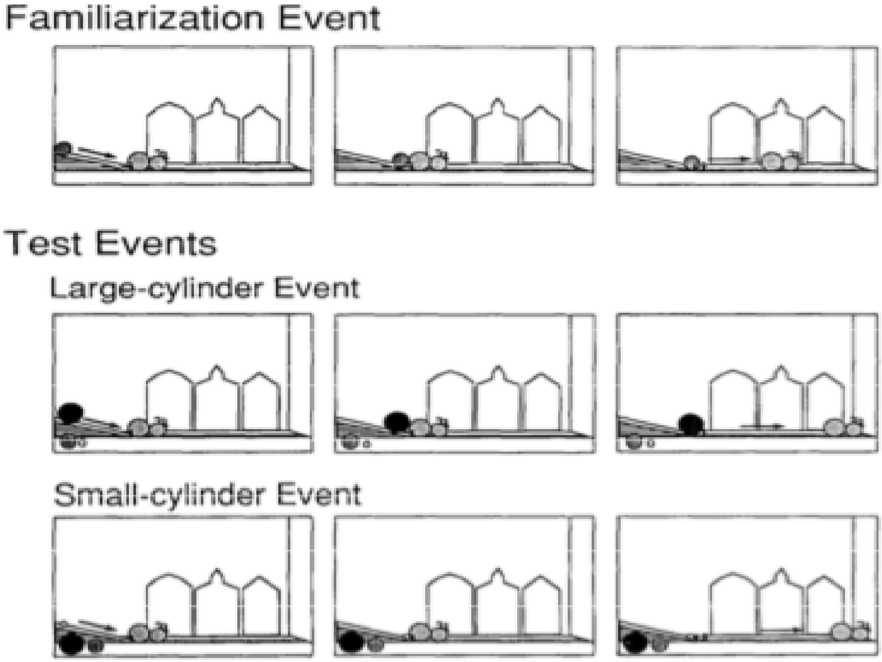
The causal impressions of collision events were first demonstrated by Michotte (1963) through a succession of experimental studies. Michotte (1963) demonstrated that the perception of causality was determined by a collection of visual cues. Causality could still be perceived by using coloured shapes or objects projected on a screen (Michotte, 1963). Michotte (1963) found that the launching effect was still perceived when the objects A and B were bright coloured spherical objects cast on a screen (Michotte, 1963). Similarly, he found that the launching effect was perceived when the object A was a wooden spherical object and object B was a bright coloured spherical object (Michotte, 1963). Later work has focused on what types of visual cues derive perception of causality in collision events (e.g., Schiff, & Detwiler, 1979; Halloun & Hestenes, 1985; Vicovaro & Burigana, 2014; Vicovaro & Burigana, 2016). For example, Schiff and Detwiler (1979) studied adults' perception of collision events involving objects of various object dimensions. Similarly, Vicovaro and Burigana (2014; 2016) studied adults' perception of collision events involving objects of various material properties.

Michotte held a nativist view on causal perception although he never conducted developmental experiments (Newman, Choi, Wynn & Scholl, 2008). Nativists' claim that humans are born with physical reasoning mechanisms that aids their further reasoning (e.g. Baillargeon, 2002). Kotovsky and Baillargeon (1998) demonstrated that 5.5 to 6 month old infants reason about object sizes and the magnitude of the force exerted by these objects on a stationary toy-bug. This inference could be driven by infants' recognition of violation rather than their actual reasoning about collision events. Empiricists on the other hand claim that humans learn through experience with the world (e.g. Hohenberger et al., 2012). For example, Hohenberger et al (2012) found 10-month-old infants to make successful matchings between size of an agent ball and propelled distance of a patient ball but not 6 month old infants. We have chosen to investigate both 6-to-7-month old and 10- to-11-month old infants. These age ranges suggest that infants have some experience with the objects around themselves. Object brightness and pitch sound that is of interest for this thesis can be experienced in the world. For example, most materials in the world become darker in colour and heavier when wet (Walker, 2012). Similarly, animals that produce a low pitch sound are usually bigger in size, thus heavier in weight (Walker, 2012). Exposure or experience to events that involve these associations might be enough to create these links between brightness and weight, and between pitch sound and weight. However, perceiving the relationship between these object properties and mass in collision events is a more complex matter.

Recent research claims that infants of 8 hours to 71 hours of age display a preference of 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 (Mascalzoni, Regolin, Vallortigare, & Simion, 2013). It is unclear whether this preference is of random nature. At the age of 2.5 months, infants start to expect that a patient object will move after a collision with an agent object, but not after a delay between the collision of the two objects (Baillargeon, 1995; Kotovsky & Baillargeon, 1994). This inference could be driven by infants' recognition of violation rather than their actual expectation about collision events. The perception of object properties and outcomes involved in causal events happens at a later age (Kotovsky & Baillargeon, 1998). Infants between 5.5 to 7 months of age consider object size in collision events (Kotovsky & Baillargeon, 1998). Kotovsky and Baillargeon (1994) first tested infants of 10.5-to-11.5 months of age on this paradigm. For testing adults' reasoning and infants' perception of object brightness and sound pitch in collision events, the methodology employed by Kotovsky and Baillargeon (1994) has been adopted with some alterations. The methodology of the present experiments in this thesis will be discussed next.

1.2.2 The methodology of the collision events

This methodology was first adopted to examine 10.5-to-11.5-month old infants' perception of object size and its cues to mass in 3D real-life collision events (Kotovsky, & Baillargeon, 1994). Next, these authors used the same methodology to examine 5.5- to- 6.5-month olds' perception of object size in 3D real-life collision events (Kotovsky, & Baillargeon, 1998). Recently, Hohenberger and colleagues (2012) replicated the experiment by Kotovsky and Baillargeon (1998) with 10-to-11- month old infants using 2D computer animated collision events. Kotovsky and Baillargeon (1994; 1998) found that infants that were previously habituated to a condition in which a mid-size cylinder propelled a patient toy-bug to the midpoint of the screen, perceived a large cylinder but not a small cylinder to propel the toy-bug to the endpoint of the screen. Hohenberger et al. (2012) demonstrated similar findings but with 10-to-11-month old infants that had a secure attachment style and had mothers that were not anxious in the lab setting. Infants in the previously mentioned experiments demonstrated this perception by looking longer at the event that violated their expectation; the event in which the small ball propelled a patient object to the endpoint of the screen (Kotovsky, & Baillargeon, 1998; Hohenberger et al., 2012). These results were based on infants' total looking times for the test events. These findings suggest infants perceive the object size and its cues to mass in 3D real-life and 2D computer animated collision events, however there are methodological limitations with the original experiment by Kotovsky and Baillargeon (1994).



Familiarization Event

Test Events

Large-cylinder Event

Small-cylinder Event

Fig 1.1. The original experiment by Kotovsky and Baillargeon (1994;1998).

In the original experiment by Kotovsky and Baillargeon (1994), infants were habituated to the condition in which a mid-size blue cylinder rolled down a ramp and either propelled a colourful toy-bug to a midpoint or to an endpoint of the screen. Next, infants viewed a large-size yellow cylinder or a small-size orange cylinder roll down a ramp and propel the colourful toy-bug to the endpoint of the screen. Kotovsky and Baillargeon (1994) found infants looked longer at the small-size cylinder test event compared to the large-size cylinder test event when habituated to the mid-point condition. This led the authors to conclude that infants perceive object size and its cues to mass in physical causal events (Kotovsky & Baillargeon, 1994). Specifically, that infants attend to the size of the agent object and perceive displacement of the patient object depending on the size of the agent object in these simple collision events. Infants perceive a greater displacement following a collision with a large object and a lesser displacement after collision with a small object. However, in the aforementioned experiment, infants were given two cues (size and colour) to distinguish between objects. The findings of this experiment can therefore not be solely attributed to size. Furthermore, in the test events the large and small size cylinder propel the toy bug to only one distance, to the endpoint of the screen. This means that infants were not presented with other distance options to compare between sizes. For these reasons, the collision events by Kotovsky and Baillargeon (1994) were modified.

Our alternative method modified these aforementioned limitations by using same coloured agent objects and including another distance option to compare between the sizes. This distance option was before the midpoint of the screen (shorter distance). Furthermore, the other modifications we made to the original experiment were; infants were habituated to the midpoint condition only, billiard balls were used instead of cylinders as only the diameter of the cylinders were noticeable in the original experiment, and the colourful toy bug was swapped to a grey cube to neutralise the events. We used 3D computer generated collision events as opposed to 3D real-life collision events for standardising purposes. In the 3D real-life collision events there is room for human error across events and participants. This human error is eliminated in the 3D computer generated collision events that follow similar design and duration across events for all participants. Our 3D computer generated collision events differed from Hohenberger and colleagues (2012) in that the balls used in our experiments were 3D pictures and set in motion by a hand which acted like an agent, balls had same grey colour, and two more test events were included (before midpoint of the screen for large and small ball). Furthermore, an impact sound was presented during collision. These changes were implemented with the aim of controlling for variables such as colour and to investigate complex momentum relationships by having both small and large size billiard balls propel a patient object to two different distances; before the midpoint and to the endpoint of the screen. This alternative method to the size-distance experiment by Kotovsky and Baillargeon (1994) was thus employed with adults and infants prior to experiments investigating object brightness and sound pitch.

The object properties brightness and pitch were examined using the same 3D computer generated collision events. However, object brightness was assessed by changing the surface brightness of the balls (white, grey and black) but keeping the balls the same mid-size. The sound-pitch was assessed by varying the impact sound during collision between low and high pitch but keeping the balls same mid-size and same grey colour. The impact sound during collision was identical for all objects in all experiments expect the test events for this experiment examining sound pitch.

1.3 Humans' perception of object properties and their cues to mass in dynamic events

1.3.1 Object properties that cue mass

Objects of various properties form the visual world (Johnson, Amso, Frank, & Shuwari, 2008). These objects vary in physical properties such as size, colour, shape, surface material, and other dimensional measurements that account for density and volume (Eckerman, Whately, & McGehee, 1979; Corter, & Jamieson, 1977). Consequently, these object properties cue for object weight and mass in adults (Wolfe, 1898; Ross, 1969; Harshfield & DeHardt ,1970; De Camp, 1917; Payne, 1958; 1961; Ross & Di Lollo, 1970; Stevens & Rubin, 1970; Anderson & Anderson, 1970; Cross & Rotkin, 1975).

These object properties cue for weight when motor actions might be involved due to the application of gravity (Hast, 2018). Similarly, they cue for mass when the amount of matter is concerned for example in visual perception of objects (Todd & Warren, 1982). However, the relationship between weight and mass is in synchrony with one another under constant gravity (Woodworth, 1921; Payne, 1958; Ross, 1969; Ross & Di Lollo, 1970; Stevens & Rubin, 1970). For example, objects of heavier weights are also greater in mass and objects of lighter weights are also lesser in mass (Woodworth, 1921). Size cues for mass, with the principle in mind that larger objects are usually perceived to be heavier in weight than smaller objects (Woodworth, 1921). Object colour in turn, has an effect as luminance cues weight; darker objects are perceived to be heavier in weight thus greater in mass than brighter objects (Payne, 1958). Density is influential in that denser materials (e.g. steel and marble) are generally perceived to be of greater mass and thus heavier in weight than less dense materials e.g. wood (Ross, 1969; Ross & Di Lollo, 1970; Stevens & Rubin, 1970).

Mass cues are essential when deriving inferences about how objects behave alone and in relation to one another (Woodworth, 1921). For this reason, adults acquire vast information about objects and exercise this knowledge in situations when anticipating and understanding physical events, directing actions on objects, understanding actions of objects (Baillargeon, 2002). It is well established that size cues for mass in both adults and infants (Woodworth, 1921; Kotovsky, & Baillargeon, 1998; 1994). For example, adults hold the view that size is positively correlated with mass with the principle that larger objects are heavier in weight and greater in mass in comparison to smaller objects (Woodworth, 1921). Similarly, infants as young as 5.5 to 6.5 months of age perceive larger objects to have greater mass, thus exert more force on a patient object, and propel it further than smaller objects (Kotovsky, & Baillargeon, 1998). Uncertainty remains whether adults reason about and infants perceive object brightness and sound pitch and their cues to mass in the collision events in a similar way to how they associate them to weight (Walker, 2012; Haryu & Kajikawa, 2012).

The object properties brightness and pitch cue weight in adults, as evidenced by findings that adults judge darker objects and low pitch sounds to be heavier in weight than brighter objects and high pitch sounds (Walker, 2012). Similarly, infants make brightness and pitch associations (Haryu, & Kajikawa, 2012). For example, infants around 10 months of age match darker objects with low pitch sounds and brighter objects with higher pitch sounds (Haryu, & Kajikawa, 2012). These pairings infants make cue for weight independently in adults (Walker, 2012). For example, the associations between dark objects and low pitch sounds cue for heavy weight in adults (Walker, 2012). Similarly, the associations between bright objects and high pitch sounds cue for light weight in adults (Walker, 2012).

These associations are a special sort of cross-sensory correspondence (Walker, 2012; Haryu & Kajikawa, 2012). Cross-sensory perception occurs when an event stimulates more than one sense (Marks, 1987; Harvey, 2013). In the case of the special sort of cross-sensory pairings between pitch and brightness, the information about the brightness of an object is expressed through visual and auditory channels. Vision provides information about surface lightness and audition about the sound pitch that the visual object emits (Walker, Walker, & Francis, 2012). For example, adults demonstrate associations between brightness and pitch (Marks, 1974; Wicker, 1968). Adults pair high-pitched sounds with brighter visual stimuli, and louder sounds with higher contrast visual stimuli (Marks, 1974; Wicker, 1968). Other cross-sensory associations involve matchings between brightness and loudness demonstrated in adults (Bond, & Stevens, 1969; Stevens, & Marks, 1965) whereby adults match light grey patches of colour with louder sounds and dark grey patches of colour with quieter sounds (Bond, & Stevens, 1969; Stevens, & Marks, 1965).Cross-sensory perception is not specifically limited to object brightness, and pitch and sound but thought to occur between various object properties (Maurer, Pathman, & Mondloch, 2006; Walker, Francis, & Walker, 2010; Ozturk, Krehm, & Vouloumanos, 2013). For example, the bouba/kiki effect is classified as a cross-sensory perception (Kohler, 1929). Adults associate the words bouba and kiki with certain shapes (Kohler, 1929). The “kiki” word is associated with angular shapes and “bouba” with curved shapes (Kohler, 1929). Furthermore, adults make cross-sensory associations between /a/and/i/ speech sounds and objects size. Adults associate the speech sound “mal” with objects of large size, and the “mil” speech sound with objects of small size (Sapir, 1929).

There is accumulated evidence to suggest that adults make associations between smaller, sharper, brighter, spatially higher visual images with high-frequency sounds (Gallace, & Spence, 2006). Similarly, adults make associations between high-pitch tones with sharp, thin, and speedily ascending visual stimuli (Gallece, & Spence, 2006; Parise, & Spence, 2009; Hubbard, 1996; Evans, & Treisman, 2009; Rusconi et al., 2006; Occelli, Spence, & Zampini, 2009; Collier, & Hubbard, 2004). Some of the associations between these cross-sensory pairs suggest a pairing based on similarity in weight and mass, but indirectly. For example, dark colours (heavy weight/more mass) are associated with low pitch sounds (heavy weight/more mass), and lighter colours (light weight/less mass) with higher pitch sounds (Bond, & Stevens, 1969; J.C. Stevens, & Marks, 1965; Marks, 1974; Wicker, 1968). Similarly, the associations between smaller (light weight/less mass), thin (light weight/less mass), brighter (light weight/less mass), with high-frequency sounds (light weight/less mass) suggest a pairing based on weight hence mass (Gallace, & Spence, 2006; Parise, & Spence, 2009; Hubbard, 1996; Evans, & Treisman, 2009; Rusconi et al., 2006; Occelli, Spence, & Zampini, 2009; Collier, & Hubbard, 2004).

Cross-sensory associations influence decision making in adults (Cytowic, 1989; Marks, 1987; Gallace, & Spence, 2006; Klapetek, Ngo, & Spence, 2012). Adults prefer events, situations, and object that match their cross-sensory associations (Cytowic, 1989). This is demonstrated by their slow response times to visual stimuli when they are paired with a distractor auditory stimuli that do not match the visual stimuli in terms of cross-sensory associations (Marks, 1987). For example, adults would be slow and less accurate when presented with a bright stimulus that is paired with a distractor auditory stimulus that is low in pitch. Similarly, adults would be slow in their response times to visual stimuli when the elevation of the visual stimulus is mismatched with pitch (Klapetek, Ngo, & Spence, 2012). For example, individuals would respond slower to a visual stimulus that is high in space when it is accompanied by a low pitch sound or low in space when accompanied by a high pitch sound (Klapetek, Ngo, & Spence, 2012). Similarly, participants find it harder to put the visual stimulus into a category in the context of its size (as either large or small) when the task-irrelevant sound on each set of trials are incongruent (e.g. when a large visual target was accompanied by a high-pitch sound), than when trials are congruent (e.g. large visual target accompanied by a low-pitch sound). However, when adults are asked to judge size when a congruent sound is presented during the trials, they are faster in their responses. For example, judgements are made faster when a small disk is paired with high frequency sounds, and a large disk is paired with low frequency sounds. For that reason, faster responses are given to congruent cross-sensory trials (e.g. high frequency sound with small disk) compared to incongruent cross-sensory trials (e.g., low-frequency sound with small disk) in line with cross-sensory associations (Gallace, & Spence, 2006). Similarly, object brightness, and pitch matchings affect adults' responses in speed discrimination tasks (Hubbard, 1996; Marks, 1987). Adults respond faster to bright coloured stimuli when they are paired with high pitch sounds, and dark coloured stimuli when paired with low pitch sounds (Hubbard, 1996; Marks, 1987).

Despite the knowledge that these cross-sensory associations persist in most cultures, it still remains unknown why they exist and what purpose they serve (Martino, & Marks, 2001; Eitan, & Timmers, 2010). For example, some cross-sensory associations cannot be explained by a specific environmental context (Spector, & Maurer, 2008). Particular shapes are not commonly displayed in particular colours, certain coloured objects or surfaces do not generally elicit specific pitch sounds (Spector, & Maurer, 2008). However, the associations related to weight can be explained by the associations humans form in the natural world (Mondloch & Maurer, 2004). For example, correspondences between object brightness and weight in humans exist in the natural world, because most materials in the world such as wood, soil, and sand become darker in colour and heavier when wet and this might be enough to create the associations (Walker, 2012). Similarly, associations between a pitch and weight may exist because animals that produce a low pitch sound are usually bigger in size, thus heavier in weight (Walker, 2012). The other cross-sensory correspondences such as shape and pitch sounds etc. challenges the idea that common exposure to these matchings of these cues explain the existence and purpose of these associations (Spector & Maurer, 2008). These cross-sensory habits cannot therefore be explained with the learning processes for these associations.

Two other possible explanations for these cross-sensory associations that cannot be explained by the environmental context might be that these associations come to exist as pairings similar to adult synaesthesia or as remnants of neonatal synaesthesia (Maurer, 1997; Maurer, & Mondloch, 2005; Haryu, & Kajikawa, 2012; Ward, & Mattingley, 2006). Adult synaesthesia is characterized as a condition in which a sensual stimulation involuntary and automatically sets off another sensory (Harvey, 2013). Throughout their lifetime, synesthetics feel words, taste colors and see sounds involuntarily and automatically (Rogowska, 2011). However, synaesthethic individuals differ between each other as there are various kinds of synaesthesia (Cytowic, 2002; Harrison & Baron-Cohen, 1997; Hochel & Milan, 2008). For example, some synaesthetes hear musical sounds when seeing colours, whereas others feel scents when seeing colours. Synaesthesia is similar to cross-sensory mappings in that similar and identical neural processes are behind both processes (Bien, Ten Oever, Goebel, & Sack, 2012). For this recognition, it has been suggested that cross-sensory correspondences and synaesthesia may lie on opposite ends of a synesthetic continuum (Bien, Ten Oever, Goebel, & Sack, 2012). Furthermore, there is evidence suggesting when visual perception emerges from sound in synaesthethic individuals, it is a case of cross-sensory processing (Ward, & Mattingley, 2006). Other researchers claim that cross-sensory mappings are innate residuals of unsuccessful differentiation of the senses (Maurer, 1997; Maurer, & Mondloch, 2005; Simner, 2012). These researchers further suggest that as newborns we are born with undifferentiated senses, a term called neonatal synaesthesia and after exposure to the world we learn to differentiate between senses (Maurer, 1997; Maurer, & Mondloch, 2005).

Cross-sensory perception is not limited to adults alone but exists and extends to children and infants as young as newborns (Maurer, Pathman, & Mondloch, 2006; Walker, Francis, & Walker, 2010; Ozturk, Krehm, & Vouloumanos, 2013; Walker et al., 2018). Newborn infants are sensitive to associations between visuospatial elevation and pitch (Walker et al., 2018). In the study of Walker et al. (2018), neonates demonstrated a sensitivity to congruency by looking longer at congruent test events (pitch fall when ball fall or pitch rise when ball rise) compared to the incongruent test events (pitch fall when ball rise or pitch rise when ball fall). Infants around 4 months of age make associations between shape and sound based on congruent and incongruent shape and sound associations (Ozturk, Krehm, & Vouloumanos, 2013). For example, infants associate the word “kiki” with angular shapes and “baluba” with round shapes (Ozturk, Krehm, & Vouloumanos, 2013). Infants of 4 months of age also make appropriate associations between vocals and body size (Pietraszewski, Wertz, Bryant, & Wynn, 2017). Larger body sizes (heavier in weight) are associated with lower pitch vocals and smaller body sizes (lighter in weight) are associated with higher pitch vocals. When 6 months of age, infants associate pitch and object size (Fernandez-Prieto, Navarra, & Pons, 2015). These findings are indirectly in line with pitch and weight associations found with adults (Walker, 2012). Infants perceive object brightness and pitch associations at 10 months of age (Haryu, & Kajikawa, 2012). Darker balls are associated with lower pitch sounds, and brighter balls are associated with higher pitch sounds. However, infants are inconsistent with the matchings between pitch sounds and size (Haryu, & Kajikawa, 2012). For example, infants in the study by Haryu and Kajikawa (2012) did not always match high frequency sounds with small objects, and low frequency sounds with large objects. Both object properties were presented with animations consisting of bouncing balls in colours (white and black) and sizes (small and large) with congruent or incongruent pitch sounds (high or low pitch).

Taken together, the aforementioned investigations demonstrate that infants make object brightness and pitch associations much later than shape, size, and sound and pitch associations (Haryu, & Kajikawa, 2012; Ozturk, Krehm, & Vouloumanos, 2013). The congruent and incongruent associations for pitch sound and object brightness are in line with appropriate weight matchings for both properties (Haryu, & Kajikawa, 2012). For example, darker colours are matched with low pitch sounds (heavy weight), and lighter colours with high pitch sounds (light weight). Uncertainty remains whether infants associate the object properties brightness and pitch based on assumed weight like adults, and when this emerges in humans first. The weight relationship is suggested as an explanation to the association between pitch and brightness, because these associations do not exist in the natural world. For example, darker coloured animals do not make lower pitch sounds.

Pre-schooled children do however consider object brightness in their assessment of object weight (Plack, & Shick, 1976). Children in this study were presented with six blocks of colours; red, blue, and yellow in varied hues (light and dark). Altogether the set consisted of light red, dark red, light blue, dark blue, light yellow and dark yellow. The children were asked to judge the weight of these six blocks and darker colours were judged to be heavier than lighter colours (Plack, & Shick, 1976). Although both young and older children of the study judged lighter colours to be lighter in weight and darker colours to be heavier in weight, the explanation of the findings for each age group differed. For example, older children of the study based the weight on the visual dimension (colours), whereas the younger children based it on the verbal cue of weight (Plack, & Shick, 1976). This remains the only study on children's perception of colour and weight.

On account of the object properties brightness and pitch in both adults and infants, it remains unclear how these object properties will cue mass independently in infants and cue mass similarly to weight in adults in the context of dynamic collision events.

1.3.2 Perception of object properties that cue mass in dynamic events

Adults consider object properties and masses in their assessments of object momentum in dynamic events (Vicovaro, & Burigana, 2014). Vicovaro and Burigana (2014) demonstrated that adults consider velocity ratios and mass cues of objects of varying sizes and material properties such as polystyrene, wood and iron in the assessment of natural and unnatural causal collision events. For example, a collision is judged to be natural or unnatural based on the pre-collision velocity of an object A and post-collision motion of an object B depending on the implied masses of the sizes and material properties of objects A and B (Vicovaro & Burigana, 2014). Larger objects and objects of material properties iron are expected to have higher masses compared to objects of material properties wood that are expected to have larger masses than polystyrene and smaller objects (Vicovaro & Burigana, 2014). Collision outcomes that regarded these expectations and displayed appropriate velocity ratios (pre-collision and post-collision velocity) were judged to be natural and collision outcomes that disregarded these expectations and displayed inappropriate velocity ratios were judged to be unnatural (Vicovaro & Burigana, 2014).

Adults also demonstrate successful matchings between size of agent object and propelled distance of patient object in collision events (Schiff, & Detwiler, 1979). Adults consider object size in two-dimensional information in momentum relationships (Schiff, &Detwiler, 1979). Judgements of collision events depends on the size of the agent and the patient object. Larger masses are thought to exert more force, therefore push an object further in collision events (Schiff, & Detwiler, 1979). Uncertainty remains about how other object properties such as object brightness and pitch that cue weight in adults are perceived in collision events. Thus, this gap remains to be explored within this thesis. A similar gap in knowledge exists in the infant literature. Apart from infants' successful link between object size and mass in collision events found by Kotovsky and Baillargeon (1998), object properties such as brightness and pitch have not been demonstrated in infants in the context of dynamic events. Nevertheless, infants demonstrate some consideration of visual and auditory object properties in momentums (Kotovsky, & Baillargeon, 1998; Bahrick, Netto, & Hernandez-Keif, 1998; Bahrick, 1988; Pickens, & Bahrick, 1995; 1997; Allen, Walker, Symonds, & Marcell, 1977; Pickens, 1994; Walker- Andrews, & Lennon, 1985).

In the real-life collision events examined by Kotovsky and Baillargeon (1998), infants between 5-to-6-months of age make appropriate matchings between size of agent object and propelled distance of patient object based on both size and sound cues presented during collision. Thus, infants' perception of object interactions is dependent on both visual and auditory information presented at the same time (Kotovsky, & Baillargeon, 1998). Visual and auditory information in dynamic events are rarely separated, because they remain unified in the multimodal world we live in (Bahrick, 1983). For example, a bouncing ball that elicits a sound every instance it contacts a surface is distinguished as an unitary event by infants (Bahrick, 1988). It is also known that infants, like adults, devote perceptual attention to objects that are moving and eliciting sounds and possess the skills to make successful discrimination between sounds based on visual stimuli (Bahrick, Netto, & Hernandez-Keif, 1998; Pickens, & Bahrick, 1995; 1997; Allen, Walker, Symonds, & Marcell, 1977; Pickens, 1994; Walker- Andrews, & Lennon, 1985). For example, infants as old as 7 months of age use tempo dissimilarities when discriminating rhythmic changes in moving objects (Pickens, & Bahrick, 1995; 1997). Furthermore, infants are successful in noticing rhythmic patterns across auditory stimuli when paired with visual display (Allen, Walker, Symonds, & Marcell, 1977). For example, infants associate objects that are approaching and receding with an increase and decrease in auditory magnitude (Pickens, 1994; Walker- Andrews, & Lennon, 1985).

Taken together, the relationship between sound and visual stimuli in infants' perception of dynamic events is integral for perceiving the entire event. However, dynamic event outcomes between objects of varying physical properties are mostly assumed in relation to mass (Woodworth, 1921), meaning that mass cues for object properties for all objects involved in collision events are considered separately, then in relation to one another to deduct dynamic event outcomes. However, in the context of this thesis, some physical properties will conflict with each other in the computer generated collision events. For example, two objects will be of same size but differ in object brightness. Similarly, two objects will be of same colour and size but differ in sound pitch during collision. The perception of physical properties of objects will thus be discussed next.

1.4 Human perception of physical properties of objects

1.4.1 Visual perception of objects and their physical properties

Humans are born with functioning oculomotor (eye movement) processes (Prechtl & Nijhuis, 1983). Already when newborn, they perceive differences between shapes (e.g. Triangles, circles, crosses and squares) and various line orientations (Slater, Morison, & Rose, 1983; Slater, Morison, & Somers, 1988). For example, newborn infants demonstrate preference for a novel shape (demonstrated by longer looking time) when paired with a familiar shape they have seen previously. Longer looking time for novel shape compared to familiar shape suggests that infants can distinguish between shapes they have seen and not seen previously (Slater, Morison, & Rose, 1983). Similarly, neonates show preference for novel line orientations, indicated by their longer looking time for these stimuli compared to looking time for a line orientation seen previously (Slater, Morison, & Somers, 1988).

Besides these accomplishments, neonates are also successful in perceiving the shape or size of an object as being constant despite differences in the angle of viewing (Slater, & Morison, 1985; Slater et al., 1990). For example, after watching an event in which the object is of constant size or shape, but the distance differs across trials, newborn infants demonstrate longer looking time at stimuli of different size and shape compared to objects of same size and shape at a different distance. This indicates that infants can detect changes in size and shape unaffected by the change of distance across stimuli (Slater, & Morison, 1985; Slater et al., 1990). These finding are pertinent to the present thesis as this is the primary object property we wish to examine in infants. Around 2 months of life, infants start to perceive object unity from motion patterns

(Johnson, & Aslin, 1995). For example, infants demonstrate longer looking time at two rod pieces (broken rod) compared to a complete rod after watching a rod motion behind a box and be occluded by the box. The longer looking time in this case suggest violation of the expectation, indicating that the expected is the complete rod. This suggests that infants perceive that a full rod is behind the box, although the occlusion of the box makes the rod look like a broken rod (Johnson, & Aslin, 1995).

Research up to this point in time suggests that infants until about 2 months of age are successful in recognising and distinguishing between physical properties of objects. However, it is thought that from about 3 months of age infants start to have a well-developed perception of physical properties of objects (Oakes & Cohen, 1990; Bremner, 2010; Baillargeon, & Graber, 1987). For the visual object property of interest to our research question, the perception of object brightness starts from about 4 months of age by infants' successful perception of colour and shape (Bushnell, & Roder, 1985). Around 4 months of age, infants perceive both colour and form (Bushnell, & Roder, 1985). For example, infants display a longer looking time at a novel combination of colour and shape compared to the familiar colour and shape combination previously seen. Longer looking time in this example indicate infants' ability to distinguish between novel and familiar colour and shape combinations (Bushnell, & Roder,1985). This response to colour and form in infants later demonstrate their use of colour at 11.5 months of age and shape to individuate objects in occlusion events at 4.5 months of age (Wilcox, 1999). Furthermore, infants of this age group individuate objects based on size at 4.5 months of age and pattern at 7.5 months of age (Wilcox, 1999). For example, infants distinguish the change of size, colour, pattern or shape across two objects (Wilcox, 1999). In four experiments, size, shape, colour or pattern were manipulated one at a time (Wilcox, 1999). Objects started with a specific size, shape, colour or pattern, moved behind an occluder, and then changed in that specific object property being examined or remained same. Infants distinguished between the object properties as indicated by their longer looking time for the trials in which change of the object property took place compared to trials in which the object property remained constant. However, the findings were mixed, infants were successful in distinguishing size and shape at 4.5 months, colour at 11.5 months, and pattern at 7.5 months of age (Wilcox, 1999).

It can be concluded that humans start to process physical object properties early on (Slater, Morison, & Rose, 1983; Slater, Morison, & Somers, 1988; Slater, & Morison, 1985; Slater et al., 1990; Johnson, & Aslin, 1995; Oakes & Cohen, 1990; Bremner, 2010; Baillargeon, & Graber, 1987). Already when newborn, they have the necessary oculomotor processes for successful perception and discrimination between various object properties (Prechtl & Nijhuis, 1983; Slater, Morison, & Rose, 1983; Slater, Morison, & Somers, 1988; Slater, & Morison, 1985; Slater et al., 1990). Perception of size and shape happen earlier than colour and pattern (Wilcox, 1999). However, infants can distinguish colour and shape combinations at 4.5 months of age (Bushnell, & Roder, 1985). It is unclear whether infants' early ability to distinguish shape at 4.5 months of age is an aid for the task involving colour and shape combinations (Wilcox, 1999; Bushnell, & Roder, 1985). Regardless of this, infants start to perceive size as newborns and colour around 4.5 months of age. Although object brightness, not object colour, is of interest for this thesis, brightness and saturation of object is linked to perception of object colour (Plack, & Shick, 1972; Gaines, 1972). For example, Gaines (1972) found elementary school children to not be skilled in colour discrimination when colour was low in saturation and brightness. Besides object size and brightness, pitch of visual objects will be assessed in this thesis. It is necessary to investigate at what age humans perceive pitch sounds successfully. Thus, the perception of sound and pitch, and tracking the location of sound will be discussed next.

1.4.2 Auditory perception and tracking location of sound

Humans are born with intact auditory processes (Winkler et al., 2009; Stefanics et al., 2009; Butterworth, & Castillo, 1976). Newborns can detect beat in rhythm in music, differentiate between pitch intervals, and direct eye gaze and the head to the location of sound (Winkler et al., 2009; Stefanics et al., 2009; Butterworth, & Castillo, 1976). For example, neonates demonstrate discriminative brain responses when infrequent beat in rhythm is detected (Winkler et al., 2009). This finding suggests that infants can detect the beat in rhythm in music by the brain as newborn (Winkler et al., 2009). Similarly, newborns discriminate between pitch intervals by their brain responses during infrequent rhythm as compared to frequent stand pitch sounds (Stefanics et al., 2009). This study marks the age in which pitch sound can be detected in infants. However, it can only be concluded from Stefanics et al., (2009) that infants discriminate between pitch intervals in their brains and not whether they attend to the location of this sound. Further support for this is presented by Butterworth and Castillo (1976). In their two experiments, they demonstrated that newborn infants can direct eye gaze and head, and track location of sound. In sum, it can be argued that detection of pitch and eye gaze to source happens very shortly after birth (Stefanics et al., 2009; Butterworth, & Castillo, 1976). However, this thesis concerns both pitch sound and visual objects. Next section will discuss human's auditory and visual perception of an event.

1.4.3 Auditory and visual perception of objects and their physical properties

Three weeks after birth, infants respond to sound loudness that matches visual stimuli being presented (Lewkowicz, & Turkewitz, 1980). For example, infants of 3 weeks of age demonstrate a cardiac response to sound loudness and visual stimuli that were similar in intensity (Lewkowicz, & Turkewitz, 1980). Infants pair high intensity visual stimuli with auditory stimuli high in intensity. Similarly, infants pair low intensity visual stimuli with auditory stimuli low in intensity (Lewkowicz, & Turkewitz, 1980). Later, around 3 months of age, infants match vocal sounds with body sizes (Pietraszewki, Werts, Bryant, & Wynn, 2017). For example, infants match larger organisms with low frequency sounds, and smaller organisms with high frequency sounds (Pietraszewki, Werts, Bryant, & Wynn, 2017). This has been evidenced by their longer looking time on visual and frequency sounds that do not match (Pietraszewki, Werts, Bryant, & Wynn, 2017). For example, infants look longer at matchings; larger organisms with higher frequency sounds, and smaller organisms with low frequency sounds (Pietraszewki, Werts, Bryant, & Wynn, 2017). Longer looking time in this experiment suggest that inconsistent relations violate infants' expectation. It is consistent with infants matching of lower/higher frequency sounds with smaller/larger organisms. Thus, this suggests a form of perception exists in infants that is similar to adults.

In line with our aim to study pitch as an object property in visual collision events, we will therefore examine the collision pitch sound that takes place during collision between the agent and the patient object. All visual stimuli will remain the same in all aspects of their visual properties for all events, but the collision pitch sound during collision will either be high or low pitch in the test events. The objects involved in collision events will be in movement. Thus, a successful pairing of visual and auditory information does not necessary mean that infants can pair these when they are in movement. Past research demonstrates that infants develop the skill to understand objects and object movements based on visual and auditory information from about 4 months of age (Spelke, 1979; Spelke, Born, & Chu, 1983). For example, infants of 4 months of age responded to the visual object and sound relationship when the object changed direction regardless of the impact with the surface (Spelke, Born, & Chu, 1983). This suggests that infants can track movement of objects based on an accompanying sound (Spelke, Born, & Chu, 1983). Infants between 3 to 6 months of age are successful in matching a soundtrack to the appropriate object hitting a surface (Bahrick, 1983; 1987; 1988; 1992). For example, infants look longer at the test trials when the soundtrack of an object hitting a surface do not match the material properties of the object among the two objects viewed (Bahrick, 1983; 1987).

Taken together, past literature suggests that infants are successful in matchings between visual and auditory information (Spelke, 1979; Spelke, Born, & Chu, 1983; Bahrick, 1983;1987; 1988;1992). Furthermore, they make pairings between a visual object in movement and accompanying sound (Spelke, Born, & Chu, 1983; Bahrick, 1983; 1987). Thus, for the purposes of this thesis, we can conclude that objects and their interactions can be tracked by infants as young as 3 months of age. This is concluded based on infants' ability to track visual objects matched with sound. Furthermore, infants possess the ability to make successful matchings between visual and auditory stimuli based on similarities as demonstrated from the empirical literature on visual and auditory information. However, it is unclear how infants would integrate this knowledge to perceive dynamic events when the physical properties of the objects and their cues to mass are assessed. Thus, the next section will address how humans perceive information in dynamic events.

1.5 Human perception of dynamic events

1.5.1 Human perception of computer generated dynamic events

Adults are successful in pairing object properties and their appropriate masses, and the momentum outcomes of these relationships in computer animated dynamic events (Vicovaro & Burigana, 2014). Similarly, infants as young as 10 months of age are successful in matchings between size of agent objects and propelled distances of patient object in computer animated collision events (Hohenberger et al., 2012). For example, infants look longer at an event in which a small agent object propels a patient object to endpoint of the screen compared to when a large agent object propels a patient object to the same distance. This finding is interesting, as infants around 5.5 to 6.5 months of age perceive the relationship between size and distance in 3D real-life collision events but not in computer animated collision events (Kotovsky, & Baillargeon, 1998; Hohenberger et al., 2012).

Hohenberger and colleagues (2012) replicated the experimental findings of Kotovsky and Baillargeon (1998) with 10-to 1- month-olds, but not with 6 to 7 month olds. In Hohenberger et al.'s (2012) experiment, a hand did not set the objects in motion. Without amendments herein, Hohenberger and colleagues (2012) replicated the experimental findings of Kotovsky and Baillargeon (1998) with 10-to-11-month olds despite the nature of their collision events. For that reason, in the present thesis, the computer generated collision events have been created with pictures of 3D real-life objects and a hand has been used to set the billiard balls in motion. The motion patterns have been adjusted using Animate C.C but follow a pattern consistent with real-life expectations.

1.5.2 Demonstration of human perception of dynamic events

Adults can make verbal judgements of dynamic events related to object properties that directly cue mass, whereas pre-lingual infants cannot (Vicovaro, & Burigana, 2014). Adults will therefore make verbal judgements of the computer generated collision events in our experiments by rating the likelihood of the events on a 1(not very likely) to 10 (very likely) Likert scale. The violation of expectation method (i.e. looking time) will be used with the infant participants. This method has been adopted in this thesis for two reasons; 1) it is an appropriate measure for infants and assesses their visual perception (Baillargeon, Spelke, & Wasserman, 1985), and 2) both the original (Kotovsky, & Baillargeon, 1998) and the animated replication experiment

(Hohenberger et al., 2012) adopted this method in studying infants' perception of collision events.

Violation of expectation was a method first adopted by Baillargeon, Spelke and Wasserman in 1985, to test infants' so called "understanding" of object permanence. Experiments using this method can for example examine infants' perception of solid objects and these objects' movements through space occupied by another solid object (Baillargeon, Spelke, & Wasserman, 1985). Infants' display of surprise when a solid object passes the space that another solid object occupies is claimed to indicate a perception of object permanence (Baillargeon, Spelke, & Wasserman, 1985), in line with the idea that infants will be surprised when an impossible event is taking place. An example of a typical violation of expectation experiment demonstrated by Baillargeon and De Vos (1991), present infants as young as 3 months of age with two carrots of different sizes (small and large). These carrots move along a track and then pass a screen that has a window. This experiment is designed so the large carrot can be noticeable in the window when passing the track but not the small carrot. Results of this experiment indicated that infants looked longer when the large carrot could not be seen in the window (impossible event) but not when the small carrot could not be seen (possible event) in the window (Baillargeon, & De Vos, 1991). Similarly, infants in the present experiments of the thesis will indicate a violation of expectation by looking longer at collision events that are not in line with their expectation. For example, infants should look longer at events in which an object of lesser mass propels a patient cube to the endpoint of the screen (impossible event), and an object of greater mass propels a patient cube to before the midpoint of the screen (impossible event). The possible events in which an object of lesser mass propels a patient cube to a location before the endpoint of the screen, and an object of greater mass propels a patient cube to the endpoint of screen will therefore be looked at less in comparison to the impossible events.

In some experiments using violation of expectation as the measure, infants are either habituated or familiarised to events. The habituation or familiarisation events are performed to inform the infants about numerous features of the test events. Once the habituation phase is completed, infants next watch test events; possible and impossible test events. Longer looking time devoted to the impossible events compared to possible events suggest that (1) infants' perception are in line with the perceived outcome; (2) infants perceive the violation of the impossible event; and (3) infants display surprise as a response to this violation (Wang, Baillargeon, & Bruckner, 2004). Thus, increased looking time has been the generally applied indicator for violation of expectation in infants (Fantz, 1967).

In our case, infants will be habituated prior to test events in line with the original experiment of Kotovsky, & Baillargeon (1998). In a typical habituation event, a stimulus is presented repeatedly and the gradual decrease in time spent looking at the stimulus across trials indicate habituation (Kagan, & Lewis, 1965). This is thought to be because repeated information is less novel, and is therefore processed less and less over repeated trials (Turk-Browne, Scholl, & Chun, 2008). Infants are considered habituated to an event when their looking time has reduced to a criterion level (for instance, that the mean looking time for last three trials is less than half of the mean looking time for the first three trials) (Cohen, & Gelber, 1975). Once the criterion level has been reached for habituation then infants start to view the test events. The stimuli shown in the test events differ from the habituation stimulus on perceptual dimensions (e.g. midpoint distance the patient object is propelled to followed by a collision with a mid-size ball versus endpoint distance the patient object is propelled to followed by a collision with either a large or small ball) and differ from each other on some critical dimensions (e.g. endpoint distance the patient object is propelled to followed by a collision with either a large or small-size ball).

Despite the common usage of the violation of expectation method, it presents a few limitations (e.g. Cohen, & Marks, 2002; Haith, 1998; Munakata, 2000; Dunn, & Bremner, 2017). The limitations are the method’s failure to replicate original findings, and misrepresentation of theoretic framework (Munkata, 2000). The failure to replicate original findings might stem from methodological differences across experiments. For example, in the original experiments, a 3D real-life block might have been used. In other experiments, a 2D block or a computer-generated block might have been used. The results might then differ across experiments based on varied reasons such as infants’ failure to perceive the 2D or computer-generated events as compellingly impossible compared to manipulated 3D real-life block or the lack of time permitted to encode the information from the events on the display (Munkata, 2000). Infants might still be familiar with the concept being tested despite their failure to perceive impossible events in 2D or computer-generated events. This might explain why the looking time for the impossible events do sometimes demonstrate a familiarity to the event (Munkata, 2000). The misinterpretation of theoretic framework is often the case when findings of experiments are interpreted with a theory that might not necessarily explain the looking time data (Munkata, 2000). For example, let us assume infants look longer at novel stimuli over familiar stimuli in our experiment. This result would be interpreted as infants perceive the change of the event. However, the wrong theory might have been applied to understand this looking time data. Alternatively, longer looking time at novel stimuli might also indicate infants' unfamiliarity to the event rather than the perception of the change of the event (Munkata, 2000).

1.6 Research objectives of the thesis

This thesis aims to examine adults' reasoning and infants' perception of object properties such as size, brightness, pitch, and their mass cues in collision events. The literature review to this point has explained the methodology of the experiments and how the experiments outlined in this thesis attempt to explain the gap in the literature for both adults and infants. For these purposes, the literature review has been conducted on collision events, object properties and their cues to mass in dynamic events, human perception of objects and their physical properties, and human perception of dynamic events. This thesis seeks to explain how adults reason and infants perceive object properties and their cues to mass in collision events.

More specifically, Chapter 3 addresses adults’ reasoning about object size, object brightness, sound pitch, and their mass cues in collision events. Participants were shown these collision events and then asked to rate the events on a scale from 1 (not very likely) to 10 (very likely). Higher rating is indicative that the outcomes of the collision events are likely.
We hypothesised that adults would rate the congruent events higher than the incongruent events. Adults would rate the events in which a large ball, dark ball and a mid-size ball accompanied low pitch sound propel a patient object to endpoint of the screen higher than when the patient object is propelled to before the midpoint of the screen. Similarly, adults would rate the events in which a small ball, bright ball and a mid-size ball accompanied high pitch sound propel a patient object to before the midpoint of the screen higher than when the patient object is propelled to the endpoint of the screen. Building on previous findings with adults, sound pitch was not further assessed with infants.

Chapter 4 investigates 6-to-7-month old infants’ perception of object size, object brightness, and object size and brightness together, and their cues to mass in collision events. Infants viewed collision events and their looking times were assessed according to the violation of expectation paradigm. We hypothesised that infants would look longer at incongruent events compared to congruent events. Infants would look longer at the events in which the large ball, dark ball and large dark ball propel a patient object to before the midpoint of the screen compared to when the patient object is propelled to the endpoint of the screen. Similarly, infants would look longer at the events in which the small ball, bright ball and small bright ball propel a patient object to the endpoint of the screen compared to when the patient object is propelled to before the midpoint of the screen. Building on previous findings with infants of 6 to 7 month of age, an older age group (10-11 months) was examined on object size in collision events.

Chapter 5 examines 10-to-11-month old infants' perception of object size of the agent and the patient object separately, and their cues to mass in collision events. Infants viewed collision events and looking times were assessed according to the violation of expectation paradigm. We hypothesised that infants would look longer at incongruent events compared to congruent events. Infants would look longer at the events in which the large ball propels a patient object to before the midpoint of the screen compared to endpoint of the screen. Similarly, infants would look longer at the events in which the small ball propels a patient object to endpoint of the screen compared to before midpoint of the screen. However, infants would look longer at the events in which a mid-size ball propels a large patient object to endpoint of the screen compared to before midpoint of the screen. Similarly, infants would look longer at the events in which a mid-size ball propels a small patient object to before the midpoint of the screen compared to endpoint of the screen.

Finally, Chapter 6 outlines the findings, and limitations of the experiments, and suggestions for future research.

Chapter 2 - General methods

This section outlines the methods used for adult and infant testing. Adults and infants were assessed differently on the computer generated collision events. Rating scales were used to assess adults and looking times were recorded to assess infants. The computer generated collision events were similar across experiments, but the object properties of the billiard balls differed across experiments. Adult participants were tested on object size, object brightness and sound pitch. Younger infants (6 to 7 months old) were assessed on object size, object brightness, and object size+brightness. Older infants (10 to 11 month olds) were examined on the object size of the agent and patient objects.

2.1 Ethical procedures and considerations

All experiments followed the APA principles and guidelines for research involving human subjects, and all procedures, participant information sheets, participant consent forms, and debriefed forms, were approved by the Lancaster University Research Ethics Committee (see Appendix A and Appendix B). In line with this, all data gathered were reduced to numbers and presented so as not to provide information about any adults' or infants' identity. Video recordings of infants were stored on an encrypted hard-drive in the Babylab, so data did not leave the building. Furthermore, participation was entirely voluntary and the participants had the right to withdraw from the study and withdraw the data up to two weeks after the participation.

Recruitment for infant testing was done via the Lancaster University Babylab. Parents were contacted through email with a short description of the study and an information sheet attached to the email. The email also provided information about each infant's participation period. Parents received travel reimbursements and the infant received a book for their participation. Adult participants were approached at campus and received refreshments for their participation.

Finally, inclusion criteria were applied. These included, by self-report: (1) normal or corrected-to-normal eyesight; (2) No form of synaesthesia; (3) No colour blindness. The inclusion criteria for infants included: (1) No form of visual impairments; (2) successful habituation; (3) watching test events after collision takes place.

2.2 Experimental set-up

Infants watched the events on a screen (789x400 px). Participants were seated 80 cm from the screen on their parent's lap. The events were at the eye level of the infants and at a 75° angle from the infants' midline. The events were presented on a 49x39 cm screen surrounded by a black cloth with 10 cm width on a black card (49x117 cm). There were two black cards on either side of the screen measuring 49x117 cm each, these were situated to attenuate light reflection and other distractions. Habit2000 software (Cohen, & Chaput, 2000) was used to time presentation and to record looking times input by the experimenter. A camera, situated through a small circular opening 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. Adults watched the events on a Macbook air 33.78 cm screen with headphones in, and verbally assessed the collision events by rating the test events on a scale from 1 (very unlikely) to 10 (very likely).

2.3 Visual stimuli

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*=789.45 px, *H*=191.45 px), background of three houses (*W*=521.85 px, *H*=208 px), ramp

(*W*=148 px, *H*=95 px), a cube (*W*=95 px, *H*=95 px), a hand (*W*=95 px, *H*=76 px), and three billiard balls with different physical properties depending on experiment.

The patient object was propelled to midpoint during habituation events. In the test events, the patient object was propelled to before the midpoint (shorter distance) or endpoint (longer distance) of screen. In the habituation events, the patient object was propelled by a billiard ball of physical properties that cued mid-mass. In the test events, the patient object was either propelled by a billiard ball of physical properties that cued greater mass (Object A1) or lesser mass (Object A2). Participants were randomly assigned to a group before the experiment and watched the events in following order:

Group one: Object A1 (congruent –incongruent) – Object A2 (incongruent-congruent)
Group two: Object A2 (incongruent –congruent) – Object A1 (congruent- incongruent)
Group three: Object A1 (incongruent –congruent) – Object A2 (congruent-incongruent)
Group four: Object A2 (congruent –incongruent) – Object A1 (incongruent-congruent)

Participants were first shown a reference or habituation event scene in which a hand was presented but the billiard ball that served as an “agent” was hidden (for 1 s). Subsequently, the hand was hidden and then present again with the “agent” billiard ball (for 1 s). The hand placed the ball on the ramp, pressing it down, and after 1 s, the hand was lifted. The ball rolled down the ramp (for 1 s) and propelled the cube that was in front of the first house to the second house (1 s). The animation continued 1 s after movement ended to allow participants time to perceive the event. Next, participants were shown test event scenes in which a hand was again presented but the billiard ball that served as an “agent” was hidden (for 1 s). Subsequently, the hand was hidden and then present again with the “agent” billiard ball (for 1 s). The hand placed the ball on the ramp, pressing it down, and after 1 s, the hand was lifted. The ball rolled down the ramp (for 1 s) and propelled the cube that was in front of the first house either to the end of the first house or to the last house (for 1-2 s). Again these events continued 1s after movement ended to allow participants the time to perceive the event in its entirety. In total, the events in which the cube propelled to the first and second house lasted 6 s (240 frames, 48 frames/s), and the 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 till the end of the first house (shorter condition). The cube travelled 1,25 cm/s from the start of the first house till the middle of the second house (midpoint condition). The cube travelled 1,17 cm/s from the start of the first house till the middle of the third house (endpoint condition).

2.4 Auditory stimuli

The auditory stimulus was the natural sound of a billiard ball hitting a wooden cube. The Audition C.C (2016), Adobe Systems was used to amplify the sound. This stimulus was used for all habituation, reference, and test events for all experiments apart from the experiment examining sound pitch with the adults. The stimulus had a duration of 0.33 s, average acoustic amplitude of 81.90 dB and an average auditory frequency of 196.50 Hz. For the pitch-mass experiment, this stimulus was changed in frequency to produce high and low pitch sounds. For these purposes, Audition C.C (2016), Adobe Systems was used, the two separate sound clips had a duration of 0.33 s. Low-pitch sound had an average acoustic amplitude of 80.43 dB and an average auditory frequency of 208.08 Hz. High-pitch sound had an average acoustic amplitude of 81.9 dB and an average auditory frequency of 571.29 Hz.

2.5 Procedure

Both adults and infants were randomly assigned to a group before the experiment and watched the events in the following order as described above in 2.3. Infants first viewed the habituation events. The habituation events were viewed until successful habituation. Infants are considered habituated to an event when their looking time has reduced to a criterion level (for instance, that the mean looking time for last three trials is less than half of the mean looking time for the first three trials) (Cohen, & Gelber, 1975). This criterion level was applied to our habituation trials. Infants were successfully habituated when the mean looking time for the last three trials were less than the half of the mean looking time for the first three trials.

One habituation trial was presented in a loop for a maximum of 60 s. The duration of the habituation trial was infant dependent, but the trial ended when the infant looked away for 2 cumulative seconds. 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 events in that specific order depending on group they were assigned to. Infants saw each test event in a loop for a maximum of 60 s. The duration of the test event was again infant dependent, but the event ended when the infants looked away for 2 cumulative seconds. A rattle was presented after the end of each test event to direct infants' attention back to the screen.

Adults viewed the test events once for 6 or 7 s depending on the length of the event. Adults were asked to rate the test events on a scale from 1 (very unlikely) to 10 (very likely) on how likely they were to happen in the real world. Next, adults viewed the habituation trial and the test events once more for 6 or 7 s depending on the length of the event. Adults were asked to rate the test events in relation to the reference event on the same rating scale. Participants were told that the reference event is the rule and asked to rate the likelihood of the other events based on this rule.

2.6 Data analyses

For infant testing, the Habit2000 software (Cohen, Atkinson, & Chaput, 2000) was used to record looking times and time presentations. The video recordings of each session were later coded and compared with looking time data. See Chapter 1 for the discussion of the limitations and the debates surrounding the interpretation of looking time data. Total looking time and looking time post-collision were the parameters extracted for infant participants. Infant data for both habituation and test events were analysed using repeated measures general linear model (GLM) after data were log transformed in IBM SPSS Statistics 23.0. Data was log transformed because looking time data are log-normally distributed across participants and should always be log transformed before statistical analyses (Csibra, Mascaro,Tatone, & Lengyel, 2016). Adults' ratings of habituation/reference and test events were analysed similarly to infant data using repeated GLM in SPSS, but the data were not log transformed. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

Chapter 3 - Adults 'reasoning about object properties and their cues to mass in collision events

Abstract

Past research suggests that adults make cross-sensory associations between object brightness, the sound pitch objects emit and object weight (Walker, 2012). Adults judge darker objects to be heavier in weight than bright coloured objects and lower pitch sounds to be heaver in weight than higher pitch sounds (Walker, Francis, & Walker, 2010; Walker, Walker, & Francis, 2012). It is unknown whether these matchings are present and cue for mass similarly in collision events. To study object brightness and sound pitch in collision events, an alternative version to Kotovsky and Baillargeon's (1998) methodology was adopted. To validate the alternative collision events, object size was examined with adults prior to object brightness and sound pitch. For these means, the present experiments examined the matchings between object size and mass, object brightness and mass, and sound pitch and mass in collision events in adults by using 3D computer-generated collision events. The results of Chapter 3 revealed that adults sometimes based their mass judgements on visual cues of objects such as object size and object brightness, but not the sound pitch in the collision events.

3.1 Introduction

Collision events contribute more in regards to perception than merely being seen as collisions between objects (Runeson, 1977; 1983). Michotte (1963) demonstrated this through a succession of experimental studies on collision events showing that the perceptual properties of the setting but not the physical properties of the objects (e.g. shape and colour etc.) involved in the collisions were influential in the perception of the launching effect. In his experiments, Michotte (1963) demonstrated the perception of launching effect was unaffected by physical properties of object A (agent object) or object B (patient object to be collided with). For example, launching effect was still perceived when shadows of object A and B were cast on the screen. Similarly, the launching effect was perceived when the object A was a wooden spherical object and object B was a bright coloured spherical object cast on a screen (Michotte, 1963). Michotte (1963) supported the idea that the perception of the launching effect is visual and unaltered by the physical properties of objects that indirectly indicate mass with his experiment findings.

Halloun and Hestenes (1985) later demonstrated that physical properties of objects that indirectly indicate mass are crucial for the perception of force and resistance in launching events (Halloun & Hestenes, 1985). For example, an object A with larger mass can exert greater force onto another object B. However, if the object B also has larger mass, then object B display a greater resistance to object A (Halloun & Hestenes, 1985). To these means, when adults are presented with collisions between two objects with varying physical properties, the pattern of the collision can be predicted by the mass cues of the object properties of the colliding objects, i.e. object A and object B (Todd & Warren, 1982). Vicovaro and Burigana (2014) found that adults anticipated a collision event to be natural or unnatural based on the velocity ratios and mass cues of size and material properties polystyrene, wood and iron of the colliding objects A and B. Adults judge a collision to be natural or unnatural based on the pre-collision velocity of object A and the post-collision motion of object B which is determined by the masses of objects A and B (Vicovaro & Burigana, 2014). Larger objects and objects made out of iron are expected to have higher masses compared to objects of wood that are expected to have larger masses than polystyrene and smaller objects (Vicovaro & Burigana, 2014). Collision outcomes that regarded these expectations and displayed appropriate velocity ratios (pre-collision and post-collision velocity) were judged to be natural and collision outcomes that disregarded these expectations and displayed inappropriate velocity ratios were judged to be unnatural (Vicovaro & Burigana, 2014).

In recent years, it has been documented that object brightness and sound pitch the object emits cue for weight in adults (Walker, 2012; Walker, Walker, & Francis, 2012). Adults judge brighter objects and higher pitch sounds to be lighter in weight, and darker objects and lower pitch sounds to be heavier in weight (Walker, 2012). Uncertainty remains about if these object properties cue for mass in collision events. We thus aim to examine object brightness and sound pitch in adults' judgment of collision events. Object brightness and sound pitch involves objects of identical dimensions. Past research has considered identical object dimensions to examine object material properties in collision events (Vicovaro & Burigana,2014; 2016). For example, Vicovaro and Burigana (2016) examined material properties wood and plasticine in collision events with identical object dimensions. To examine object brightness and sound pitch in collision events we adopted our alternative method to Kotovsky and Baillargeon's (1998) experiment that examined object size in collision events. An experiment investigating object size in collision events was performed first to validate the alternative method we suggested to Kotovsky and Baillargeon's (1998) collision event experiment.

The results of the experiments examining object size, object brightness and pitch sound in collision events will attempt to demonstrate if these object properties cue for mass similarly to weight in adults. Furthermore, the findings from these experiments will attempt to demonstrate how adults process perceptual information in collision events, as ambiguity remains concerning this subject. Some researchers claim information coming from various origins can be integrated by the cognitive system (e.g. Anderson, 1983). In contrast, others suggest the cognitive system is limited for integrating information from various origins thus individuals would base judgements of collision events on the salient characteristic of the event (Proffitt & Gilden, 1989). The object properties size and brightness are salient visual cues in the experiments testing these properties. However, sound pitch is examined with a visual object that is identical in object brightness and size across test events. The sound pitch during collisions varies and is indicative of mass cues in line with adults' sound pitch and weight associations in the cross-sensory literature mentioned earlier (Walker, 2012). It is therefore vital that adults possess the ability to integrate auditory and visual information during the viewings of the collision events. Warren, Kim and Husney (1987) demonstrated that adults are successful in integrating auditory and visual information for object elasticity during collision events. The findings of this experiment support the view that information from various modalities, visual and auditory information in this case is redundant (Warren, Kim, & Husney, 1987).

The intersensory redundancy hypothesis suggests that information presented through two or more modalities amplifies the perception of the whole event whereas information through one modality amplifies the perception of that modality specific event (Lickliter, Bahrick, & Vaillant-Mekras, 2017). This means that the difference between the sensory characteristics of visual and auditory information does not interfere with the perception of an event (Gibson, 1969). There are alternative views on redundant information, as some claim the visual system is dominant thus dominates the auditory system or that visual and auditory information need to match regards to sensory characteristics to be perceived (Warren, Kim, & Husney, 1987). The experiment examining sound pitch is therefore sensitive to adults' successful integration of auditory and visual information to view the collision event.

Experiment 1: Object size as a cue to mass in collision events

Experiment 1 tested adults' judgements of object size and its cues to mass in collision events. Adults first saw four collision events (test events) and were asked to rate how real life based they were (real-life based likeliness of events). Next, adults saw the reference event and were asked to rate the test events in relation to the reference event (reference related likeliness of events). In the reference event, adults watched a mid-size grey billiard ball propel the grey cube to midpoint of the screen. Test events showed large or a small-size grey billiard ball propel the grey cube to a size-appropriate distance (congruent) and a size-inappropriate distance (incongruent). The congruent outcomes were the ones in which the small-size grey billiard ball propelled the cube to before the midpoint, and the large-size grey billiard ball propelled the cube to endpoint of the screen. Similarly, incongruent outcomes were the ones in which the small-size grey billiard ball propelled the cube to endpoint and the large-size grey billiard ball propelled the cube to before midpoint. In all events a sound was presented during collision. This sound was produced by striking a billiard ball against a wooden cube. These collision events were rated on a Likert scale from 1 (very unlikely) to 10 (very likely). Higher ratings corresponded to agreement with outcome of collision events. We thus hypothesised that congruent events would be rated higher than incongruent events based on object size.

3.2 Experiment 1: Method

3.2.1 Participants

A total of 24 participants between ages 23 years and 36 years (*M*=27.46, *SD*=4.25) took part in the experiment. 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 females (*M*=26, *SD*=4.03) and 12 males (*M*=28.42, *SD*=4.42) were subdivided (*F*=3, *M*=3) into four groups (*N*=6 per group), to counterbalance the order of the test events.

3.2.2 Materials and apparatus

Events were created as outlined in Chapter 2 of this thesis. Billiard balls were of sizes small (*W*=40 px, *H*=40 px), medium (*W*=60 px, *H*=60 px), and large (*W*=90 px, *H*=90 px) in this experiment (see Fig 3.1 and 3.2).

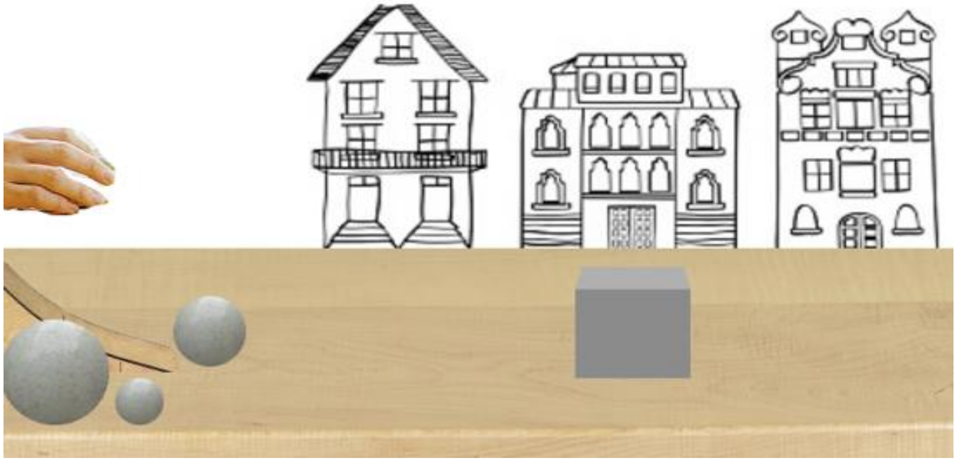


Fig 3.1. This collision event involving the medium ball served as reference event.

The billiard balls hit the cube and made it propel to either the size appropriate (congruent) or the size inappropriate (incongruent) distance (see Fig 3.2).

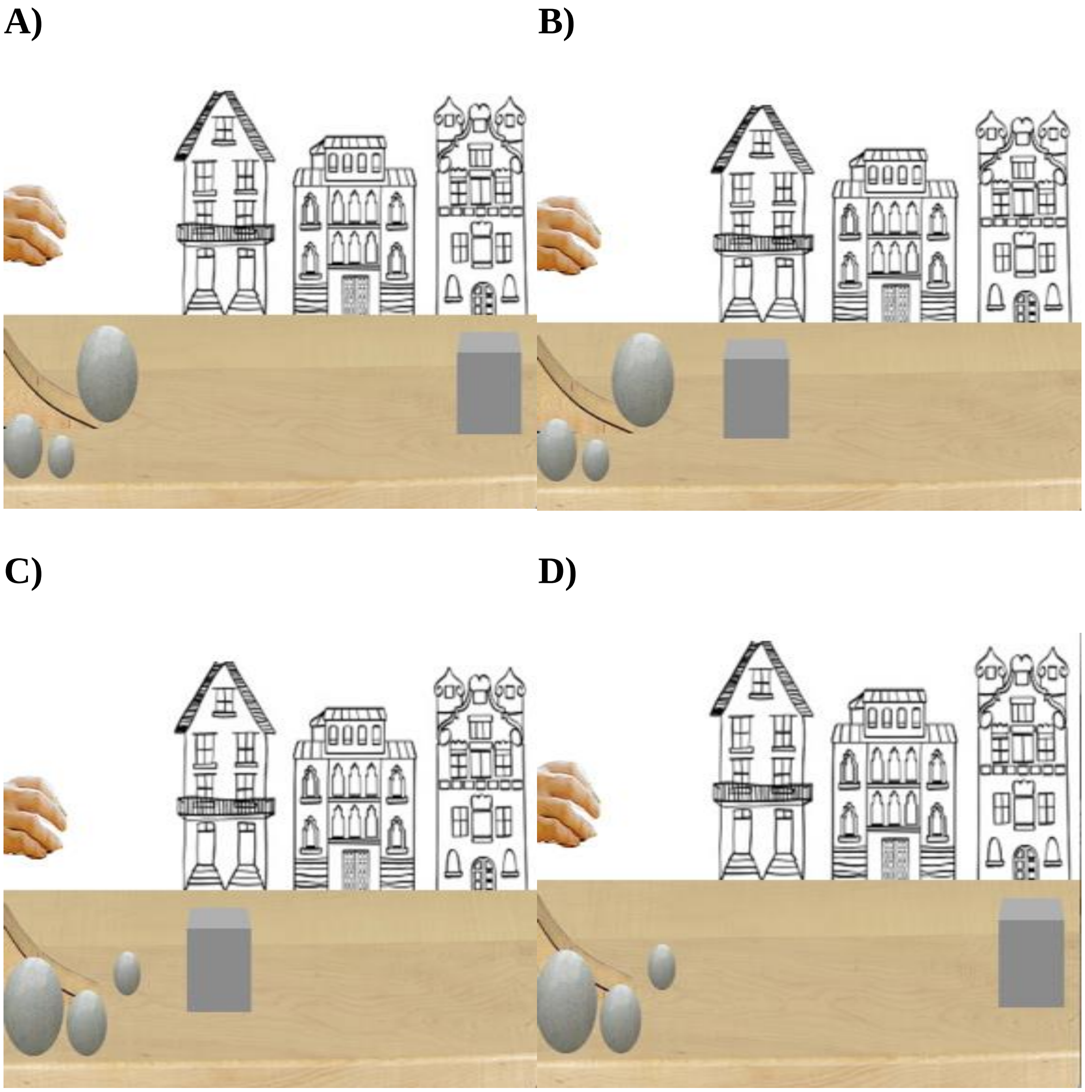


Fig 3.2. From top to bottom: Top: (A) Large ball congruent, (B) Large ball incongruent, Bottom: (C) Small ball congruent, (D) Small ball incongruent event.

3.2.3 Procedure

Following participants' consent to take part in the experiment after being informed about the experiment, participants were subdivided (*M*=3, *F*=3) into four groups (*N*=6) and viewed the events shown on Fig 3.2 in following sequences:

Group one: A-B-C-D

Group two: B-A-D-C

Group three: C-D-A-B

Group four: D-C-B-A

Dependent on group, adults viewed the computer-generated collision events in that specific order. Participants were first asked to rate the test events on a scale from 1 (very unlikely) to 10 (very likely) on how likely they were to happen in the real world. Next, the reference event was presented, and participants were asked to rate the test events in relation to the reference event on the same rating scale. Participants were told that the reference event is the rule and asked to rate the likelihood of the other events based on this rule. The instructions and the rating scale were repeated prior to each test event. Ratings were documented in a notebook under the specific code the participants were allocated in the beginning of the experiment. Upon completion participants received refreshments and debrief forms explaining the purpose of the experiment.

3.3 Experiment 1: Results

Rating data were analysed separately for real-life based and reference related likeliness of test events with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with size (large or small) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

3.3.1 Real-life based likeliness of test events

3.3.1.1 Primary analysis

Analysis revealed a significant main effect for congruency, *F*(1,16)=8.31, *p*=.01, n_{p2}=.34. Adults rated the congruent test events (*M*=5.48) higher compared to incongruent test events (*M*=3.58). A significant main effect of size existed, *F*(1,16)=24.81, *p*<.001, n_{p2}=.61. Adults gave higher ratings to large ball events (*M*=5.56) compared to small ball events (*M*=3.50). The interaction effect between size and congruency was significant, *F*(1,16)=10.85, *p*<.01, n_{p2}=.40. As displayed in Fig 3.3, adults gave significantly (*p*<.001) higher ratings to the small ball congruent event (*M*=5.29) compared to small ball incongruent event (*M*=1.71). However, adults did not differ in their ratings (*p*=.86) between large ball congruent event (*M*=5.67) and large ball incongruent event (*M*=5.46).

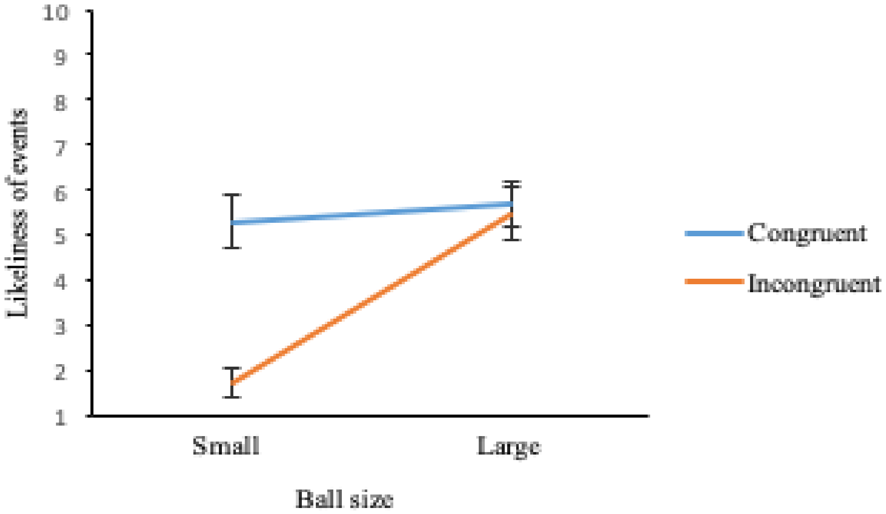


Fig 3.3. Real-life based likeliness mean ratings of small and large ball congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.3.1.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)= 0.58, *p*=.64, n_{p2}=.10 nor for gender, *F*(1,16)=0.03, *p*=.96, n_{p2}=.07. No significant interaction effect was present between gender and order group, *F*(3,16)=0.91, *p*=.46, n_{p2}=.15. There was no significant interaction between congruency and gender, *F*(1,16)=3.98, *p*=.06, n_{p2}=.20 nor congruency and order group , *F*(3,16)=2.03, *p*=.15, n_{p2}=.28. There was no significant interaction effect for order group and size, *F*(3,16)=0.40, *p*=.76, n_{p2}=.07 nor gender and size, *F* (1,16)=0.02, *p*=.88, n_{p2}=.02.

There was no significant three-way interaction for size, gender and order group, *F*(3,16)=0.92, *p*=.45, n_{p2}=.15 nor congruency, gender and order group, *F*(3,16)=0.44, *p*=.74, n_{p2}=.03, size, congruency and gender, *F*(3,16)=0.71, *p*=.56, n_{p2}=.12, size, congruency and order group, *F*(3,16)=2.13, *p*=.14, n_{p2}=.29. No significant four-way interaction for size, congruency, gender and order group was demonstrated, *F*(3,16)=0.44, *p*=.73, n_{p2}=.08.

3.3.2 Reference related likeliness of test events

3.3.2.1 Primary analysis

Analysis revealed a significant main effect for congruency, *F*(1,16)=24.69, *p*<.001, n_{p2}=.61. Adults rated the congruent test events (*M*=7.13) higher compared to incongruent test events (*M*=2.67). A significant main effect of size existed, *F*(1,16)=12.40, *p*<.01, n_{p2}=.44. Adults gave higher ratings to large ball events (*M*=5.31) compared to small ball events (*M*=4.48). The interaction effect between size and congruency was not significant, *F*(1,16)=0.00, *p*=1, n_{p2}<.01.

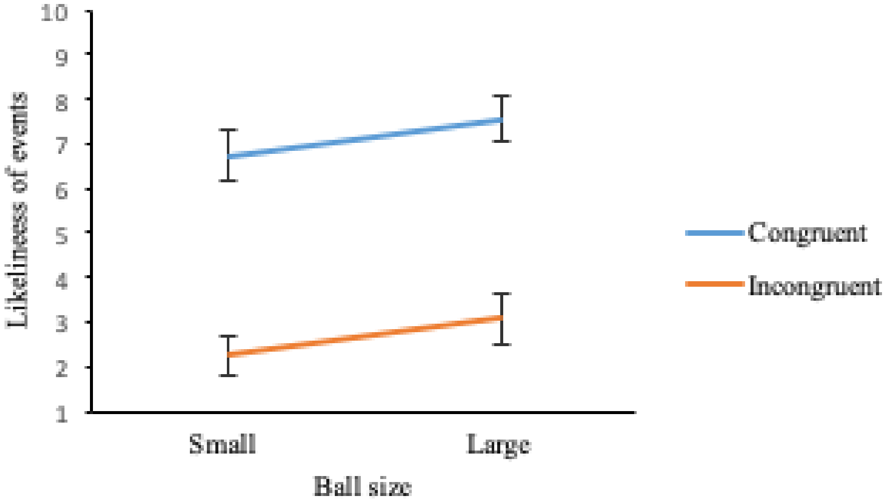


Fig 3.4. Reference related likeliness mean ratings of small and large ball congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.3.2.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)=1.12, *p*=.37, n_{p2}=.25 nor for gender, *F*(1,16)=0.78, *p*=.39, n_{p2}=.08. There was no significant interaction effect between gender and order group, *F*(3,16)=0.92, *p*=.44, n_{p2}=.15. Furthermore, there was no significant interaction effect between congruency and gender, *F*(1,16)=0.08, *p*=.78, n_{p2}=.02 nor congruency and order group, *F*(3,16)=0.56, *p*=.65, n_{p2}=.10. Similarly, there was no significant interaction effect for order group and size, *F*(3,16)=1.12, *p*=.37, n_{p2}=.17 nor gender and size, *F*(1,16)=0.78, *p*=.39, n_{p2}=.05.

Three-way interactions for size, gender and order group, *F*(3,16)=0.69, *p*=.57, n_{p2}=.12, congruency, gender and order group, *F*(3,16)=1.56, *p*=.24, n_{p2}=.23, size, congruency and gender, *F*(1,16)=0.01, *p*=.91, n_{p2}=.09, size, congruency and order group, *F*(3,16)=0.74, *p*=.54, n_{p2}=.12

were not significant. Similarly, the four-way interaction effect between size, congruency, gender and order group was not significant, *F*(3,16)=0.71, *p*=.56, n_{p2}=.12.

3.4 Experiment 1: Explanation of findings

Ratings of real-life based and reference related likeliness of events suggest that adults are sensitive to the size-appropriate and size-inappropriate distances the cube is propelled to by the small and large ball. Adults gave higher ratings to congruent test events compared to incongruent test events in line with our hypothesis. Furthermore, adults gave higher ratings to large ball test events compared to small ball test events. However, the interaction between size and congruency for real-life based related likeliness of events suggest that adults differ in their ratings between the congruent and incongruent test event for small ball. .Adults rated the small ball congruent event higher than small ball incongruent event. This finding suggests that adults sometimes use size to judge mass in collision outcomes.

In sum, the findings suggest that adults in Experiment 1 sometimes consider mass cues of object size in collision events.

Experiment 2: Object brightness as a cue to mass in collision events

Experiment 2 assessed adults' judgement of object brightness and its cues to mass in collision events. This experiment followed near identical procedure and experimental design to Experiment 1. The only change was the dimension and colour of the billiard balls. Billiard balls followed an identical dimension to the mid-size billiard ball in Experiment 1, but differed in colour (white, grey and black). Black colour was used as a cue for more mass and white as a cue for less mass in line with the literature by Walker (2012). The brightness-appropriate distances (congruent) for the bright ball (white) was the shorter distance (before midpoint) and for the dark ball (black) was the longer distance (endpoint). We hypothesised that congruent events would be rated higher than incongruent events.

3.5 Experiment 2: Method

3.5.1 Participants

A total of 24 participants took part in the experiment between ages 19 years to 30 years (*M*=24.13, *SD*=2.79). 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 female (*M*=25.42, *SD*=2.64) and 12 were male (*M*=22.83, *SD*=2.37).

3.5.2 Materials and apparatus

Animations followed similar dimensions, method and design to Experiment 1. However, all billiard balls had the identical dimension to the mid-size ball in Experiment 1 (*H*=60 px, *W*=60 px). Besides this change, billiard balls in test events differed in colour (white or black). See Fig 3.5.

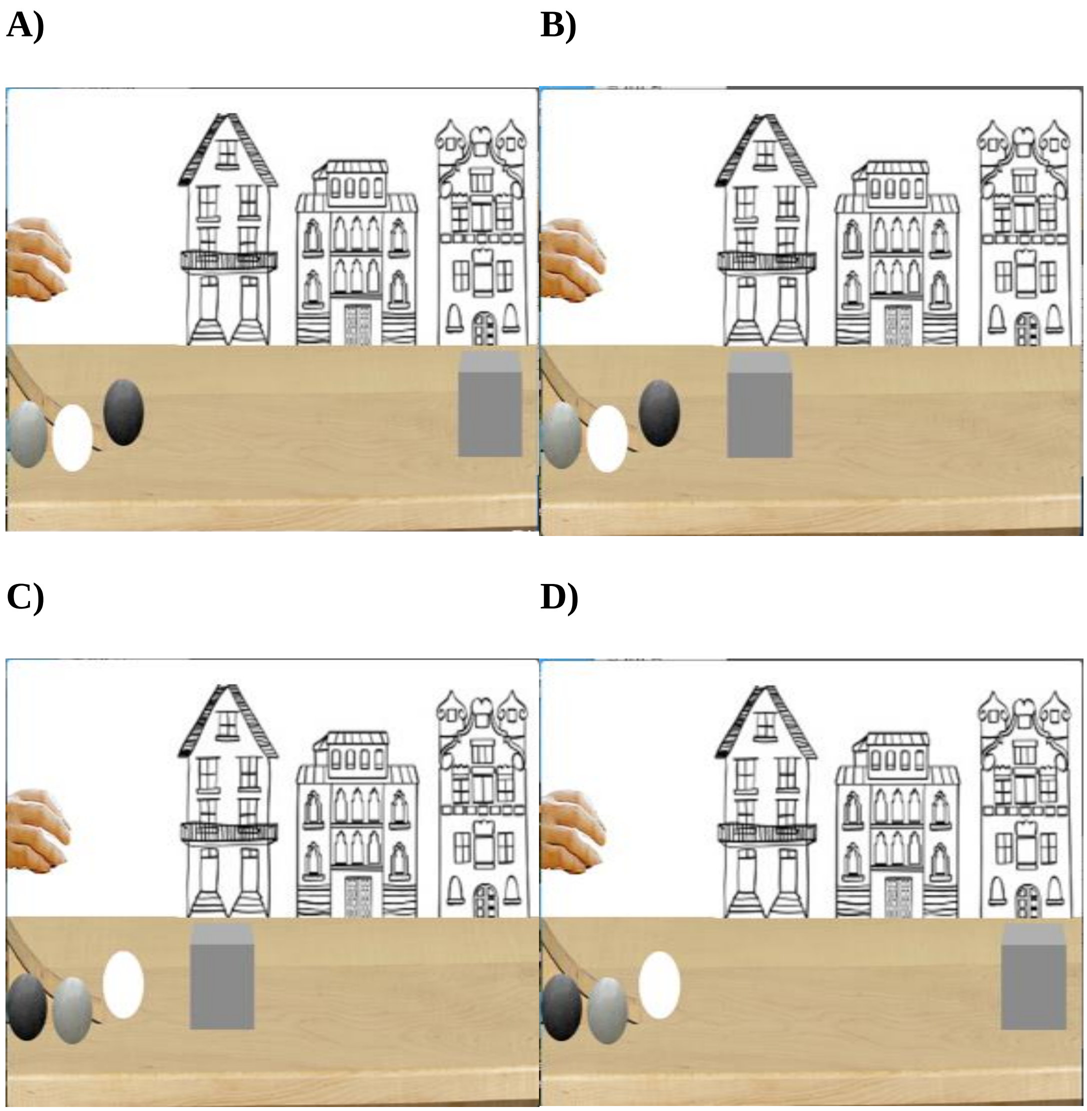


Fig 3.5. From top to bottom: Top: (A) Dark ball congruent, (B) Dark ball incongruent, Bottom: (C) Bright ball congruent, (D) Bright ball incongruent event.

3.5.3 Procedure

The procedure was identical to the one of Experiment 1. Participants were subdivided into these groups and viewed the events shown on Fig 3.5 in following sequences:

Group one: A-B-C-D

Group two: B-A-D-C

Group three: C-D-A-B

Group four: D-C-B-A

3.6 Experiment 2: Results

Rating data were analysed separately for real-life based and reference related likeliness of test events with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with brightness (dark or bright) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

3.6.1 Real-life based likeliness of test events

3.6.1.1 Primary analysis

Analysis revealed a significant main effect for congruency, *F*(1,16)=5.26, *p*=.04, n_{p2}=.25. Adults rated the congruent test events (*M*=5.71) higher compared to incongruent test events (*M*=4.46). Analysis revealed no significant main effect for brightness, *F*(1,16)=2.21, *p*=.16, n_{p2}=.12. The interaction effect between brightness and congruency was significant, *F*(1,16)=22.98, *p*<.001, n_{p2}=.59. As displayed in Fig 3.6, adults gave significantly (*p*<.001) higher ratings to the bright ball congruent event (*M*=6.83) compared to bright ball incongruent event (*M*=2.92). However, adults did not differ in their ratings (*p*=.11) between dark ball congruent event (*M*=4.58) and dark ball incongruent event (*M*=6.00).

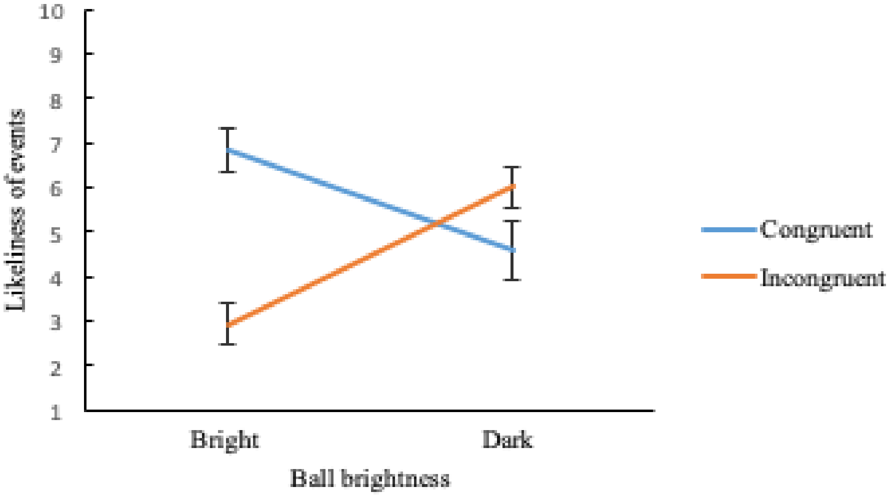


Fig 3.6. Real-life based likeliness mean ratings of bright and dark ball congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.6.1.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)=0.26, *p*=.86, n_{p2}=.08 nor for gender, *F*(1,16)=2.80, *p*=.11, n_{p2}=.15. There was no significant interaction effect for gender and order group, *F*(3,16)=0.53, *p*=.07, n_{p2}=.06. Furthermore, there was no significant interaction effect for congruency and gender, *F*(1,16)=0.05, *p*=.83, n_{p2}=.02 nor congruency and order group, *F*(3,16)=0.79, *p*=.52, n_{p2}=.13. Similarly, there was no significant interaction effect for order group and brightness, *F*(3,16)=0.62, *p*=.61, n_{p2}=.10 nor gender and brightness, *F*(1,16)=1.08, *p*=.31, n_{p2}=.06.

There was no significant three-way interaction for brightness, gender and order group, *F*(3,16)=0.55, *p*=.65, n_{p2}=.09 nor congruency, gender and order group, *F*(3,16)=0.40, *p*=.76, n_{p2}=.07, brightness, congruency and gender, *F*(1,16)=0.05, *p*=.83, n_{p2}=.03, brightness, congruency and order group, *F*(3,16)=0.49, *p*=.69, n_{p2}=.09. No significant four-way interaction for brightness, congruency, gender and order group was present, *F*(3,16)=0.95, *p*=.44, n_{p2}=.15.

3.6.2 Reference related likeliness of test events

3.6.2.1 Primary analysis

Analyses revealed a significant main effect for congruency, *F*(1,16)=45.81, *p*<.001, η_{p2}=.74. Adults gave higher ratings to congruent test events (*M*=6.73) compared to incongruent test events (*M*=2.92). Analysis revealed a significant main effect for brightness, *F*(1,16)=6.45, *p*=.02, η_{p2}=.29. Adults gave significantly higher ratings to dark ball events (*M*=5.10) compared to bright ball events (*M*=4.54). The interaction effect between brightness and congruency was not significant, *F*(1,16)=0.39, *p*=.54, η_{p2}=.02.

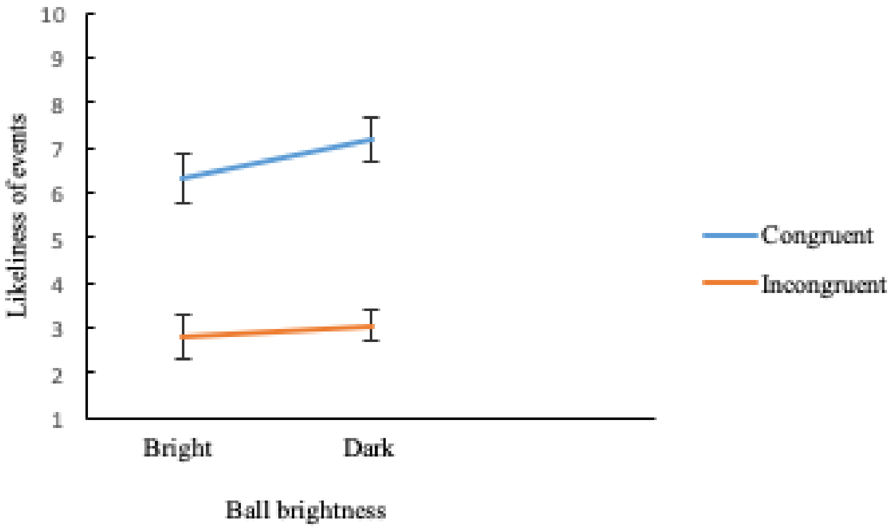


Fig 3.7. Reference related likeliness mean ratings of bright and dark ball congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.6.2.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)=0.89, *p*=.47, η_{p2}=.14 nor for gender, *F*(1,16)=1.24, *p*=.28, η_{p2}=.08. There was no significant interaction effect for gender and order group, *F*(3,16)=0.62, *p*=.61, n_{p2}=.10. No significant interaction effect for congruency and gender, *F*(1,16)=1.68, *p*=.21, n_{p2}=.10 nor congruency and order group, *F*(3,16)=2.72, *p*=.08, n_{p2}=.34 was present. Furthermore, no significant interaction effect for order group and brightness, *F*(3,16)=1.54, *p*=.24, n_{p2}=.22 nor brightness and gender, *F*(1,16)=1.50, *p*=.24, n_{p2}=.09 was present.

There was no significant three-way interaction effect for brightness, gender and order group, *F*(3,16)=0.17, *p*=.91, n_{p2}=.03 nor congruency, gender and order group, *F*(3,16)=0.38, *p*=.77, n_{p2}=.07, brightness, congruency and gender, *F*(1,16)<.0.001, *p*=.97, n_{p2}<.01, brightness, congruency and order group, *F*(3,16)=2.82, *p*=.07, n_{p2}=.35. No significant four-way interaction for brightness, congruency, gender and order group was present, *F*(3,16)=1.76, *p*=.20, n_{p2}=.25.

3.7 Experiment 2: Explanation of findings

Ratings of real-life based and reference related likeliness of events suggest that adults are sensitive to the brightness-appropriate and brightness-inappropriate distances the cube is propelled to by the bright and dark ball. Adults gave higher ratings to congruent test events compared to incongruent test events in line with our hypothesis. However, the interaction between brightness and congruency for real-life based related likeliness of events suggest that adults differ in their ratings between the congruent and incongruent test event for bright ball. Adults rated the bright ball congruent event higher than bright ball incongruent event. This finding suggests that adults sometimes use brightness to judge mass in collision outcomes. The ratings for the reference related likeliness of events suggest that adults differ in their ratings between bright and dark ball. Adults rated the dark ball test events higher than bright ball test events.

In sum, the findings suggest that adults in Experiment 2 sometimes consider mass cues of object brightness in collision events.

Experiment 3: Pitch as a cue to mass in collision events

Experiment 3 examined adults' judgement of pitch sound during collision and its cues to mass in collision events. This experiment was similar in procedure and experimental design to Experiment 2. The dimension of the billiard balls (mid-size) were identical to the billiard balls in Experiment 2, but identical in colour (grey) to Experiment 1. The collision sound for test events differed. A low pitch sound was used as a cue for greater mass, and a high pitch sound was used as a cue for lesser mass, in line with the literature by Walker (2012). The pitch-appropriate distances (congruent) for the high pitch sound was the shorter distance (before midpoint) and for the low pitch sound was the longer distance (endpoint). We hypothesized that congruent events would be rated higher in comparison to incongruent events.

3.8 Experiment 3: Method

3.8.1 Participants

A total of 24 participants took part in the experiment between ages 18 years to 64 years (*M*=28.21, *SD*=10.61). 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 female (*M*=29.83, *SD*=8.47) and 12 were male (*M*=26.58, *SD*=12.57).

3.8.2 Materials and apparatus

Animations followed similar dimensions, method and design to Experiment 2. However, all billiard balls were the same colour as the billiard balls in Experiment 1 (grey; Fig 3.8). Besides this change, the sound during collision in test events differed (high or low pitch). For test events, the sound during collision for reference event was pitched high and low to create two separate sound clips with a duration of 0.33 s. Low-pitch sound had an average acoustic amplitude of 80.43 dB and an average auditory frequency of 208.08 Hz. High-pitch sound had an average acoustic amplitude of 81.9 dB and an average auditory frequency of 571.29 Hz. A pilot (N=5) investigation confirmed that the low pitch, mid pitch and high pitch collision sounds were perceived equally loud. Each participant listened to the sound clips and changed the amplitude in either direction till they agreed they were all equally loud. The dB for each participants were noted down and compared across.The average dB from all participants were used for the sound files.

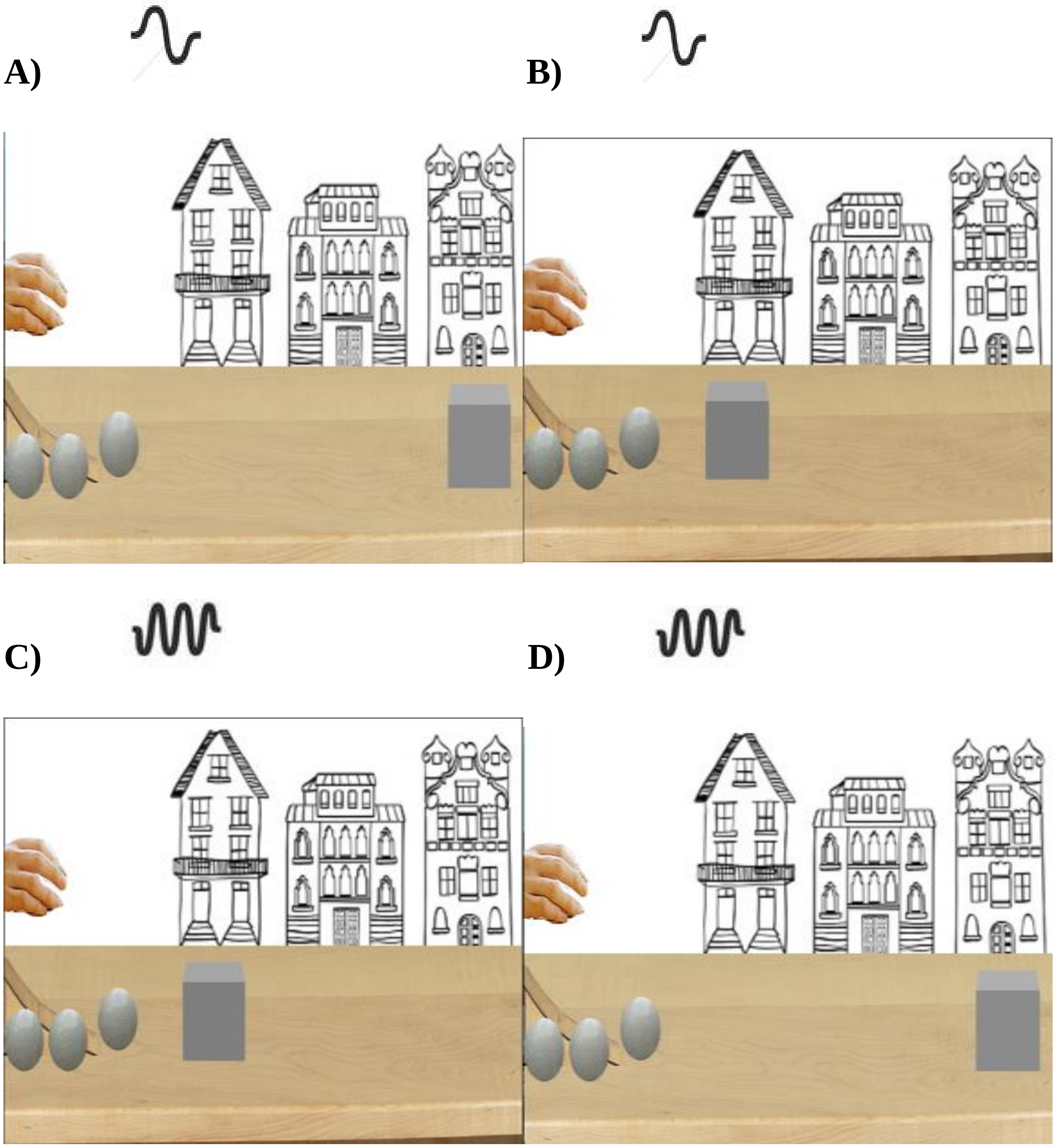


Fig 3.8. From top to bottom: Top: (A) Low pitch congruent, (B) Low pitch incongruent, Bottom: (C) High pitch congruent, (D) High pitch incongruent event.

3.8.3 Procedure

Other than the sound manipulation, the procedure was the same as in Experiment 2. Participants were divided into following groups and viewed the events shown on Fig 3.8 in following sequences:

Group one: A-B-C-D

Group two: B-A-D-C

Group three: C-D-A-B

Group four: D-C-B-A

3.9 Experiment 3: Results

Rating data were analysed separately for real-life based and reference related likeliness of test events with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with pitch (low or high) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

3.9.1 Real-life based likeliness of test events

3.9.1.1 Primary analysis

Analysis revealed no significant main effect for congruency, $F(1,16)=0.21$, $p=.65$, $n_{p2}=.01$. The main effect for pitch was not significant, $F(1,16)=0.60$, $p=.45$, $n_{p2}=.04$. The interaction between pitch sound and congruency was significant, $F(1,16)=49.78$, $p<.001$, $n_{p2}=.76$. As displayed in Fig 3.9, adults rated the low pitch incongruent event ($M=7.25$) significantly higher ($p<.001$) compared to the low pitch congruent event ($M=2.71$). However, the high pitch congruent event ($M=7.25$) was rated significantly higher ($p<.001$) compared to the high pitch incongruent event ($M=2.46$). These are an effect of travel distance with a preference for the shorter distance.

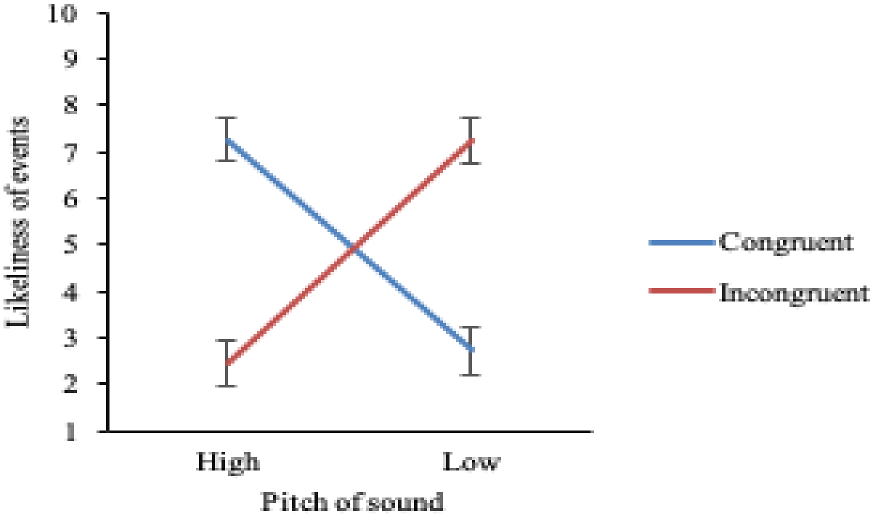


Fig 3.9. Real-life based likeliness mean ratings of high and low pitch congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.9.1.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)=0.56, *p*=.65, n_{p2}=.05 or gender, *F*(1,16)=1.43, *p*=.25, n_{p2}=.08. There was no significant interaction effect for gender and order group, *F*(3,16)=1.63, *p*=.22, n_{p2}=.23. Furthermore, there was no significant interaction effect for congruency and gender, *F*(1,16)=1.17, *p*=.30, n_{p2}=.07 nor congruency and order group, *F*(3,16)=1.18, *p*=.35, n_{p2}=.18. There was no interaction effect for order group and pitch, *F*(3,16)=2.60, *p*=.09, n_{p2}=.33 nor gender and pitch, *F*(1,16)=0.07, *p*=.80, n_{p2}=.02.

There was no significant three-way interaction for pitch, gender and order group, *F*(3,16)=1.71, *p*=.21, n_{p2}=.24 nor congruency, gender and order group, *F*(3,16)=1.31, *p*=.31, n_{p2}=.20, pitch, congruency and gender, *F*(1,16)=0.14, *p*=.71, n_{p2}=.01, pitch, congruency and order group, *F*(3,16)=0.38, *p*=.77, n_{p2}=.07. No significant four-way interaction for pitch, congruency, gender and order group was present, *F*(3,16)=1.09, *p*=.38, n_{p2}=.17.

3.9.2 Reference related likeliness of test events

3.9.2.1 Primary analysis

Analysis revealed no significant main effect for congruency *F*(1,16)=0.27, *p*=.61, n_{p2}=.02 nor for pitch, *F*(1,16)=2.33, *p*=.15, n_{p2}=.13. The interaction between pitch and congruency was not significant, *F*(1,16)=1.76, *p*=.20, n_{p2}=.10.

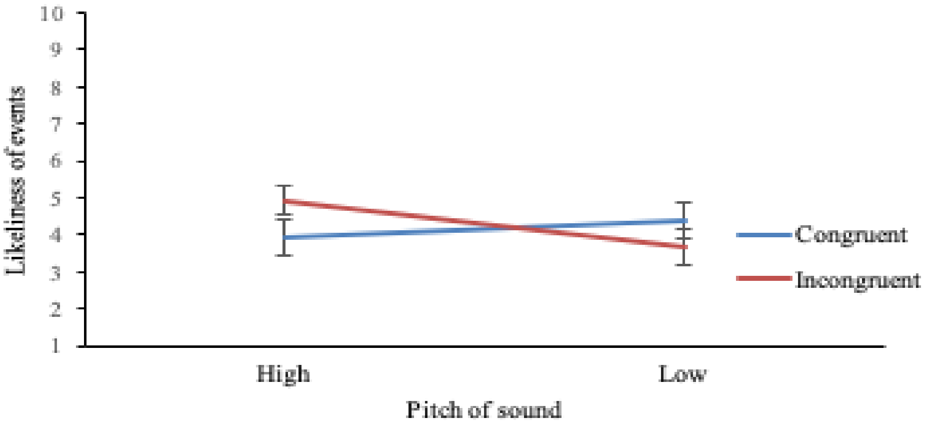


Fig 3.10. Reference related likeliness mean ratings of high and low pitch congruent and incongruent test events. Data are presented as mean ratings of likeliness and standard error of mean.

3.9.2.2 Secondary analysis

No significant main effect was present for order group, *F*(3,16)=0.86, *p*=.48, n_{p2}=.14 nor for gender, *F*(1,16)=0.67, *p*=.43, n_{p2}=.04. No significant interaction effect was present between gender and order group, *F*(3,16)=0.13, *p*=.94, n_{p2}=.06. Furthermore, no significant interaction effect between congruency and gender, *F*(1,16)=1.60, *p*=.22, n_{p2}=.09 nor order group and congruency, *F*(3,16)=1.94, *p*=.17, n_{p2}=.27 was present. There was no significant interaction effect between order group and pitch, *F*(3,16)=1.93, *p*=.17, n_{p2}=.27 or between gender and pitch, *F*(1,16)=4.03, *p*=.06, n_{p2}=.20.

There was no significant three-way interaction for pitch, gender and order group, *F*(3,16)=1.19, *p*=.34, n_{p2}=.18 nor congruency, gender and order group, *F*(3,16)=1.35, *p*=.30, n_{p2}=.20, pitch, congruency and gender, *F*(1,16)=1.60, *p*=.23, n_{p2}=.09, pitch, congruency and order group, *F*(3,16)=0.14, *p*=.94, n_{p2}=.03. No significant four-way interaction for pitch, congruency, gender and order group was present, *F*(3,16)=1.14, *p*=.36, n_{p2}=.18.

3.10 Experiment 3: Explanation of findings

Ratings of real-life based likeliness of test events suggest that there is an effect of travel distance with a preference for the shorter distance. Adults rated the shorter distance for both high and low pitch sounds higher compared to longer distance. Apart from these findings, the ratings for real-life based and reference related likeliness of test events indicate that adults did not consider the mass cues of the high and low pitch sounds in the collision events. Our hypothesis was not supported by the ratings obtained from real-life based and reference related likeliness of events.

In sum, the findings suggest that adults in Experiment 3 fail to consider mass cues of pitch sound in collision events.

3.11 Chapter 3 discussion

Findings from Chapter 3 indicate that adults sometimes attended to the visual cues of objects such as size and brightness in the collision events. Adults appear to sometimes have considered object size and brightness as a cue to mass in the collision events, but failed to do so for sound pitch. The hypothesis is supported for Experiment 1 and 2.

Previous studies have considered object properties such as size and material properties polystyrene, wood and iron in collision events (Vicovaro, & Burigana, 2014; Teixeira & Hecht, 2014), but not brightness and pitch. However, object brightness and sound pitch is reported to cue weight in adults (Walker, 2012a; 2012b). Walker (2012) did not consider the context of collision events however. Based on Walker's (2012) findings concerning object brightness and sound pitch, adults in our experiments should display similar effects in their judgements of collision events irrespective of comparisons (real-life based or reference related likeliness of events). However, methodologies in Chapter 3 of this thesis and those of Walker (2012) differ. Experiment 1, 2, and 3 required that adults integrate the knowledge of object properties into the context of collision events and judge outcomes based on these object properties. Participants in the Walker (2012) investigation were required to judge weight of objects based on properties brightness and sound pitch without further integration. Judgement of the collision events based on these object properties are thus complex because of conflicting properties that cue for mass in collision events.

Assessing object brightness in collision events means controlling for properties other than brightness. In our experiments we kept size of the objects constant. However, object brightness and its cues to mass can be overridden by the prominent relationship between size and mass in this context. This was not the case in this thesis nor in other experiments that assessed object material properties in collision events by using same size billiard balls (Vicovaro, & Burigana, 2014; Teixeira & Hecht, 2014). Similarly, in our experiment examining collision sound pitch, we kept the size of the billiard balls constant. According to Walker (2012), adults pair large visual stimuli with low pitch sound and small visual stimuli with high pitch sound. For that reason, our visual stimuli might have created a mismatch with the sound pitch presented during collision. This might further explain the lack of findings for Experiment 3 in this chapter. Another explanation to the Experiment 3 findings might be that the visual information overshadowed the auditory information that cued mass (Warren, Kim, & Husney, 1987). Adults in our experiment displayed a preference for shorter distance for all test events regardless of pitch sound. Adults rated the shorter distance for both high and low pitch sounds higher compared to longer distance. This could mean that visual information about the object thus its same size and colour would be attended to in preference to auditory information across events (low or high pitch collision sound). Attendance to visual information that is consistent through events would result in the assumption that test events are identical. Alternatively, one reason pitch did not work could be that the pitch of the contact sounds is a product of both objects and not just the launch object so it is not a reliable cue to launch object mass.

Limitations

The task of judging collision events based on pitch sounds might have been ambiguous or complex for adults. Another limitation might be that the computer generated collision events were not in line with complex physical laws. The billiard balls in the animations did not rotate and the balls moved at a constant speed across all experiments. However, the computer generated collision events were designed with the purpose to test infants, thus followed similar methodology to Kotovsky and Baillargeon’s (1998) experiment with some minor changes.

Conclusion

Chapter 3 indicates that adults hold different expectations of object properties size, brightness and sound pitch in collision events. Adults sometimes attend to and expect certain collision outcomes based on visual cues of object properties such as size and brightness, but not sound pitch.

Chapter 4 – Young infants' perception of object properties and their cues in collision events

Abstract

Infants start to make perceive size-mass relations in simple collision events around 5.5 to 6.5 months of age (Kotovsky, & Baillargeon, 1998). They perceive the size of the agent object and perceive a greater displacement of a patient object followed by a collision with a larger object relative to a smaller object (Kotovsky, & Baillargeon, 1998). It is unknown whether infants perceive outcomes of collision events based on other object properties than size. Past research suggest that pre-school children judge darker colours to be heavier than brighter colours (Plack & Shick, 1976). However, it remains unclear whether infants perceive object brightness similarly to pre-schooled children or if infants perceive object brightness in collision events and perceive an outcomes of collision events based on mass cues of brightness. To study object brightness in collision events, a revised version of Kotovsky and Baillargeon's (1998) collision scenario was used. In order to confirm the revised version, object size was tested prior to object brightness in infants. Furthermore, infants were assessed on the joint match between size and object brightness in collision events to examine the strength of two cues for mass. For these purposes, the present experiments assessed the size-mass, brightness-mass, and size+brightness-mass associations in collision events in 6 to 7 month old infants, adopting 3D computer-generated collision events. Results from Chapter 4 indicate that these experiments fail to provide evidence that infants perceive mass cues of object properties size, brightness, and size and brightness in collision events.

4.1 Introduction

Principles of physical causality are claimed to be present very shortly after birth (Mascalzoni, Regolin, Vallortigare, & Simion, 2013). Babies of 8 hours to 71 hours 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 (Mascalzoni, Regolin, Vallortigare, & Simion, 2013). At the age of 2.5 months, infants start to perceive that a patient object will move after a collision with an agent object, but not after a delay between the collision of the two objects (Baillargeon, 1995; Kotovsky & Baillargeon, 1994). The perception of object properties and outcomes involved in causal events happens at a later age (Kotovsky & Baillargeon, 1998).

Infants make size and distance associations in collision events around 5.5 to 6.5 months of age (Kotovsky, & Baillargeon, 1998). Infants perceive the size of agent object and perceive a certain momentum outcome depending on the size of the agent object (Kotovsky, & Baillargeon, 1998). For example, infants of 5.5 to 6.5 month of age perceive larger objects to propel a patient object to a further distance than a smaller object in collision events (Kotovsky, & Baillargeon, 1998). These findings were demonstrated in the experiment by Kotovsky and Baillargeon (1998) 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 (Kotovsky & Baillargeon, 1998). 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 test event (Kotovsky & Baillargeon, 1998).

Similar results are obtained with computer animated collision events with infants of 10 months of age (Hohenberger et al., 2012). These computer animated collision events differ from the original experiment by Kotovsky and Baillargeon (1998) in regard to the motion of the objects. In the original experiment (Kotovsky & Baillargeon, 1998), 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 (2012) 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 experiment by Hohenberger et al (2012) did not produce similar results with 6 month old infants, but did so with 10 month old infants. Regardless of this, both these experiments demonstrate that infants perceive object size of the agent object in collision events and perceive certain outcomes of the patient object depending on the size of the agent object (Kotovsky & Baillargeon, 1998; Hohenberger et al., 2012).

It is well-established that size cues for mass with the principle that larger objects are perceived to be greater in mass than smaller objects (Woodworth, 1921). As evidenced by the experiments from Kotovsky and Baillargeon (1998), and Hohenberger et al (2012), larger objects (greater in mass) are perceived to make a patient object propel further than a smaller object (less in mass). Mass cues aid perception, expectation, learning and understanding of object interactions (Woodworth, 1921). Given that infants base their perception of object behaviour and interaction on size which is an indirect measure of mass in collision events, there is a need to examine other potential object properties that cue mass in infants (Kotovsky & Baillargeon, 1994;1998; Hohenberger et al., 2012).

There is some evidence that suggests infants are successful in discriminating between object weight haptically (Molina, Guimpel & Jouen, 2006; Striano & Bushnell, 2005). Infants learn to discriminate object weight early on in their lives, already when newborn they acquire the skills to haptically notice and discriminate object weights (Molina, Guimpel & Jouen, 2006). This is demonstrated by changes in neonates holding times, exerted pressure and frequency of exerted pressure across light and heavy objects (Molina, Guimpel & Jouen, 2006). Not only do they display this skill in light rooms with the aid of visual cues but also in a dark environment (Striano & Bushnell, 2005). 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 experiments (Kotovsky & Baillargeon, 1998; Hohenberger et al., 2012). In these experiments, the visual discrimination between object masses based on object size has been examined in a context in which an object has an impact on another object, in a collision event.

Infants have demonstrated certain associations between other object properties and masses (Haryu & Kajikawa, 2012), but not been assessed on these object properties independently in collision events. Infants associate pitch and brightness based on assumed weight (Haryu, & Kajikawa, 2012). Infants of 10 months of age associate darker colours with lower pitch sounds (both heavier in weight) and brighter colours with higher pitch sounds (both lighter in weight). It is documented that pre-schooled children judge darker colours to be heavier in weight than brighter colours (Plack, & Shick, 1976). For that reason, it makes sense to examine object brightness and its cues to mass in collision events. Our aim is thus to examine if 6-to-7-month-old infants perceive object brightness in collision events and percieve outcomes of collision events based on mass cues of this object property. This age group is targeted based on their previous successful link between size and mass in collision events (Kotovsky, & Baillargeon, 1998).

The original experiment by Kotovsky and Baillargeon (1998) presents limitation as discussed in Chapter 1, thus will be revised as mentioned in Chapter 1 and follow the methodology outlined in Chapter 2. Our revised methodology will need further validation with the infant sample, thus infants will be tested on object size prior to object brightness in collision events. Furthermore, the strength of the relationship between size and brightness cues for mass will be assessed with infants. This means that infants will be presented with two cues (size and brightness) for mass in collision events (large dark object and small bright object).

Experiment 4: Infants’ perception of object size in collision events

Experiment 4 examined infants' perception of collision events based on size of agent object similar to the adult Experiment 1 in Chapter 3. However, the Experiment 4 differed from the Experiment 1 in following ways; infants viewed the habituation event (reference event in adult experiments) in a loop till successful habituation, and infants’ looking time was recorded for these events. Longer looking times are assumed to indicate a violation of the infant’s expectations. Thus, we hypothesized that infants will display longer looking times at events that are incongruent (size-inappropriate distances) compared to congruent events (size-appropriate distances). Incongruent events are events in which either a large ball propels a patient object to a shorter distance or a small ball propels a patient object to a longer distance. Conversely, congruent events are events in which either a large ball propels a patient object to a longer distance or a small ball propels a patient object to a shorter distance.

Experiment 4: Method

4.2.1 Participants

A total of 56 participants took part in the experiment, but due to equipment failure (*N*=5), fussiness (*N*=3), failure to habituate (*N*=17) and successful habituation but failure to watch the test events after collision took place (*N*=15), the final sample consisted of 16 participants. The 16 participants were aged between 181 days and 210 days (*M*=194.94, *SD*=10.77). 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 (*M*=193.25, *SD*=8.94) and 8 were male (*M*=196.63, *SD*=12.74).

4.2.2 Materials and apparatus

The materials and apparatus were similar to those of Experiment 1 in Chapter 3 with some differences as mentioned for infant testing in Chapter 2.

4.2.3 Procedure

Following parental consent to take part in the experiment after being informed about the experiment, 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 in Chapter 3.

Infants first viewed the habituation events. The habituation events were viewed until successful habituation. One habituation trial was presented in a loop for a maximum of 60 s. The duration of the habituation trial was infant dependent, but the trial ended when the infant looked away for 2 cumulative seconds. 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 events in that specific order depending on group they were assigned to. Infants saw each test event in a loop for a maximum of 60 s. The duration of the test event was again infant dependent, but the event ended when the infant looked away for 2 cumulative seconds. A rattle was presented after the end of each test event to direct infants’ attention back to the screen.

4.3 Experiment 4: Results

Total looking time and looking time post-collision were the parameters extracted for test events. Total looking time is the time the infant spent looking at the entire test event. Post-collision looking time is the time the infant spent looking from the collision between agent and patient object onwards till the start of the next loop. Total looking time and looking time post-collision were analysed with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with size (large or small) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

4.3.1 Test events

The total and post-collision looking time data for test events were not normally distributed thus a log transformation was performed prior to the analyses. The raw total and post-collision looking time data for test events is reported in Fig 4.1 and Fig 4.2.

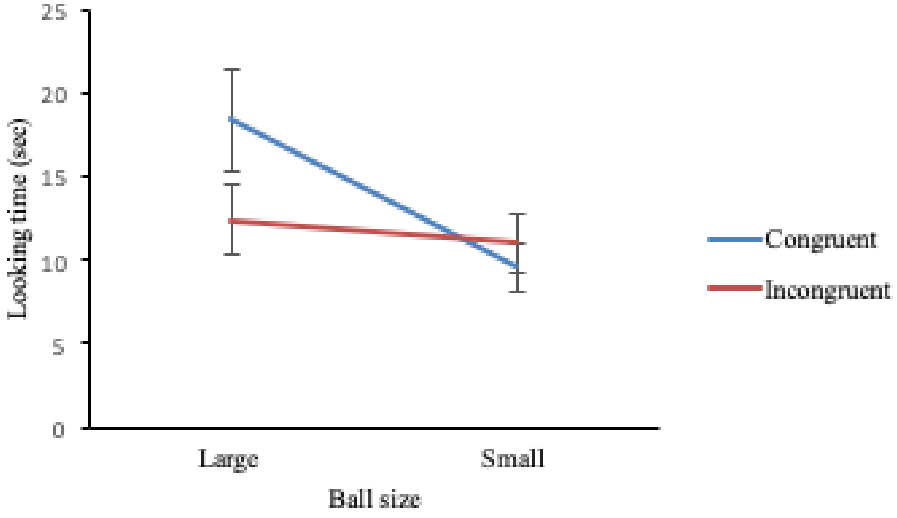


Fig 4.1. Raw mean total looking time for large and small ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

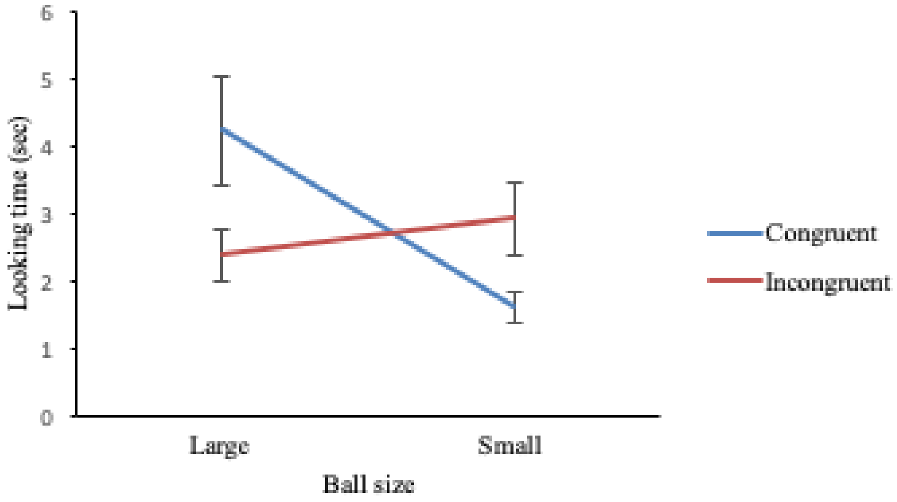


Fig 4.2. Raw mean post-collision looking time for large and small ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

4.3.2 Total looking time for test events

4.3.2.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.83, *p*=.39, n$_{p2}$=.09. Analysis revealed a significant main effect for size, *F*(1,8)=18.55, *p*<.01 n$_{p2}$=.70. Infants looked longer at the large ball test events (*M*=1.10) in comparison to small ball test events (*M*=.95). The interaction between size and congruency was not significant, *F*(1,8)=2.22, *p*=.17, n$_{p2}$=.22.

4.3.2.2 Secondary analysis

There was no significant main effect for order group, *F*(3,8)=0.74, *p*=.67, n$_{p2}$=.17 nor for gender, *F*(1,8)=0.66, *p*=.44, n$_{p2}$=.08. Similarly, the interaction between group and gender was not significant, *F*(3,8)=0.20, *p*=.89, n$_{p2}$=.07. No interaction effects for size and order group, *F*(3,8)=2.72, *p*=.12, n$_{p2}$=.51 nor size and gender, *F*(1,8)=0.01, *p*=.95, n$_{p2}$=.09 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=1.62, *p*=.26, n$_{p2}$=.38 nor congruency and gender, *F*(1,8)=0.11, *p*=.75, n$_{p2}$=.01 was present.

The three-way interactions between size, congruency and order group, *F*(3,8)=0.55, *p*=.66, n$_{p2}$=.17 and between size, congruency and gender, *F*(1,8)=0.18, *p*=.69, n$_{p2}$=.02 , size, order group and gender, *F*(3,8)=1.66, *p*=.25, n$_{p2}$=.38, congruency, order group and gender, *F*(3,8) =1.80, *p*=.23, n$_{p2}$=.40 were not significant. The four-way interaction between size, congruency, order group and gender, *F*(3,8)=0.27, *p*=.85, n$_{p2}$=.09 was not significant.

4.3.3 Post-collision looking time for test events

4.3.3.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.07, *p*=.80, n$_{p2}$=.01. Analysis revealed a significant main effect for size, *F*(1,8)=24.43, *p*<.01 n$_{p2}$=.75. Infants looked longer at the large ball test events (*M*=0.41) in comparison to small ball test events (*M*=0.27).

The interaction between size and congruency was significant, *F*(1,8)=9.89, *p*=.01, n_{p2}=.55. Infants looked significantly (*p*=.02) longer at the small ball incongruent event (*M*=.39) compared to the small ball congruent event (*M*=0.15). Moreover, infants looked significantly (*p*=.02) longer at the large ball congruent event (*M*=0.51) compared to the small ball incongruent event (*M*=0.39). These are an effect of travel distance with a preference for the longer distance.

4.3.3.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=0.71, *p*=.57, n_{p2}=.21 nor for gender, *F*(1,8)=0.15, *p*=.71, n_{p2}=.02 was exposed. Similarly, the interaction between group and gender was not significant, *F*(3,8)=0.14, *p*=.93, n_{p2}=.05. No interaction effect for size and order group, *F*(3,8)=3.25, *p*=.08, n_{p2}=.55 nor size and gender, *F*(1,8)=0.46, *p*=.52, n_{p2}=.06 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=0.98, *p*=.45, n_{p2}=.27 nor congruency and gender, *F*(1,8)=0.13, *p*=.72, n_{p2}=.02 was demonstrated.

The three-way interaction between size, congruency and order group, *F*(3,8)=0.46, *p*=.72, n_{p2}=.15 and between size, congruency and gender, *F*(1,8)=0.14, *p*=.71, n_{p2}=.02, size, order group and gender, *F*(3,8)=0.94, *p*=.47, n_{p2}=.26, congruency, order group and gender, *F*(3,8)=1.15, *p*=.39, n_{p2}=.30 were not significant. The four-way interaction between size, congruency, order group and gender, *F*(3,8)=0.41, *p*=.75, n_{p2}=.13 was not significant.

4.3.4 Total looking time for test events of non-habituated infants

Our testing sample consisted of a large number of infants who failed to habituate and were further excluded from the final analysis (*N*=17). Four infants among these 17 failed to look at the test events after collision took place and were further excluded. The remaining sample consisted of 13 infants that failed to habituate but watched all test events successfully. We examined whether these non-habituated infants (*N*=13) differed in their looking time across incongruent and congruent test events for small and large ball.

We performed another general linear model repeated measures with gender as a between-subjects factor and size (large or small) and congruency (congruent or incongruent) as within-subjects factors.

The total looking time data for test events for non-habituated infants were not normally distributed thus a log transformation was performed prior to the analyses. The raw total looking time data for test events for non-habituated infants is reported in Fig 4.3.

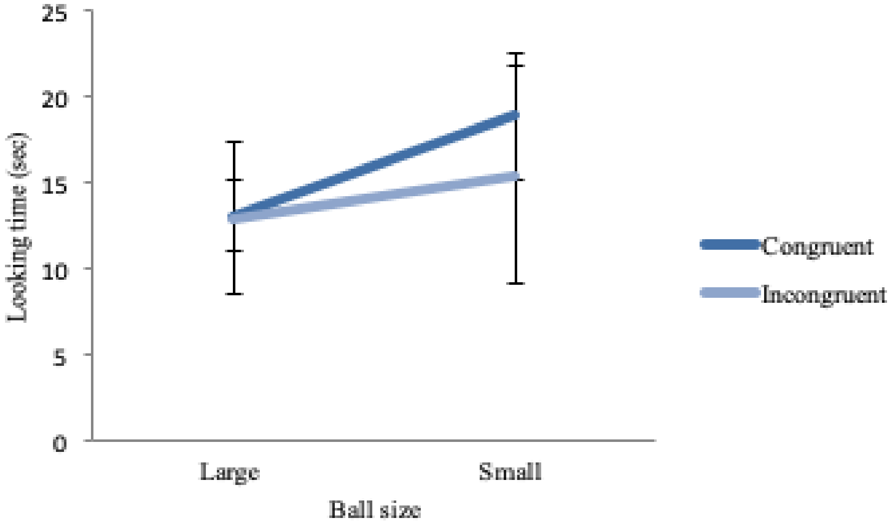


Fig 4.3. Raw mean total looking time for large and small ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

4.3.5 Total looking time for test events

Analysis revealed no significant main effect for congruency, $F(1,27)=0.37$, $p=.55$, $n_{p2}=.07$. Non-habituated infants did not differ in their looking time between congruent and incongruent test events. Analysis revealed no significant main effect for size, $F(1,27)=0.31$, $p=.58$, $n_{p2}=.05$.The interaction between size and congruency was not significant, $F(1,27)=0.83$, $p=.37$, $n_{p2}=.06$. There was no significant three-way interaction between size, congruency and gender, $F(3,27)=0.01$, $p=.93$, $n_{p2}=.05$.

4.4 Experiment 4: Explanation of findings

Results from post-collision looking time analysis suggest that there is an effect of travel distance with a preference for the longer distance. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. Besides these findings, the results obtained from Experiment 4 do not support our hypothesis that suggested infants would display longer looking times at incongruent events compared to congruent events.

Infants looked longer at the large ball test events compared to small ball test events in total and post-collision looking analyses of test events. Various explanations can clarify infants' longer looking times at large ball test events. Longer looking time can indicate surprise, violation of expectation, preference or an interest for large ball test events. Non-habituated infants did not differ in their looking time for congruent and incongruent test events.

The results produced from 6 to 7 month old infants in Experiment 4 suggest that infants between 6 and 7 months of age fail to perceive the mass cues of object size in the collision events contrary to our hypothesis.

Experiment 5: Infants' perception of object brightness in collision events

Infants' perception of object brightness in collision events was investigated despite the findings with object size in collision events for two reasons. The primary reason being the neonatal synaesthesia and cross-sensory literature that suggests that certain associations exist in young age as a result of undifferentiated senses (Maurer, 1997; Maurer & Mondloch, 2005), for example, the visual shape- sound matchings (Ozturk, Krehm, & Vouloumanos, 2013). However, brightness and mass associations to my knowledge has not been studied with infants. This association could yet exist in younger age groups. The second reason is that adults have been successful in their pairings of movement and object material properties despite the balls being of same size (Vicovaro & Burigana, 2014). For that reason, object size and brightness can be treated as individual properties, meaning that one property might work whereas the other one might fail to work with infants.

Experiment 5 investigated infants' perception of collision events based on brightness of agent object similar to adult Experiment 2 in Chapter 3. However, infants were tested following similar methods to Experiment 4. We further hypothesised that infants would look longer at incongruent (brightness-inappropriate distances) compared to congruent (brightness-appropriate distances) test events.

4.5 Experiment 5: Methods

4.5.1 Participants

A total of 44 participants took part in the experiment, but due to failure to habituate (*N*=17) and successful habituation but failure to watch the test events after collision took (*N*=11), the final sample consisted of 16 participants. The 16 participants were between ages 185 days to 204 days (*M*=194.38, *SD*=6.73). Participants were recruited from the database at Lancaster

University Baby-lab. Participants were healthy, full-term infants and received a book for their participation alongside being reimbursed for travelling costs. Of these 16 infants, 8 were female (*M*=195.13, *SD*=6.47) and 8 were male (*M*=193.62, *SD*=7.35).

4.5.2 Materials and apparatus

Materials were identical to Experiment 2 in Chapter 3 and the apparatus was identical to Experiment 4.

4.5.3 Procedure

Procedure was identical to Experiment 4.

4.6 Experiment 5: Results

Total looking time and looking time post-collision were the parameters extracted for test events. Total looking time is the time the infant spent looking at the entire test event. Post-collision looking time is the time the infant spent looking from the collision between agent and patient object onwards till the start of the next loop. Total looking time and looking time post-collision were analysed with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with brightness (dark or bright) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

4.6.1 Test events

The total and post-collision looking time data for test events were not normally distributed thus a log transformation was performed prior to analyses. The raw total and post-collision looking time data for test events is reported in Fig 4.4 and Fig 4.5.

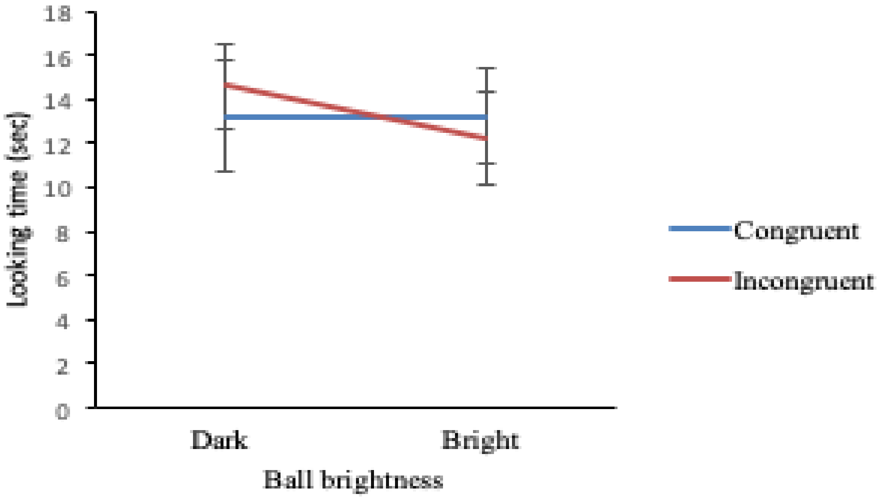


Fig 4.4. Raw mean total looking time for dark and bright ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

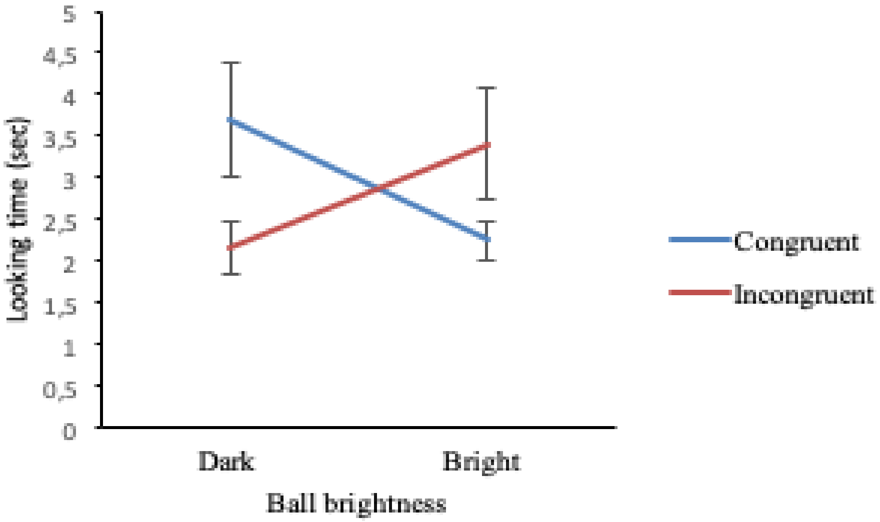


Fig 4.5. Raw mean post-collision looking time for dark and bright ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

4.6.2 Total looking time for test events

4.6.2.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.03, *p*=.88, n_{p2}=.01. Infants did not differ in their looking time for congruent and incongruent test events. Analysis revealed no significant main effect for brightness, *F*(1,8)=0.01, *p*=.92, n_{p2}=.01.The interaction between brightness and congruency was not significant, *F*(1,8)=0.23, *p*=.65, n_{p2}=.03.

4.6.2.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=2.69, *p*=.12 n_{p2}=.50 nor for gender, *F*(1,8)=0.85, *p*=.38, n_{p2}=.10 was demonstrated. Similarly, the interaction between order group and gender was not significant, *F*(3,8)=0.65, *p*=.61, n_{p2}=.20. No interaction effect for brightness and order group, *F*(3,8)=0.91, *p*=.48, n_{p2}=.25 nor brightness and gender, *F*(1,8) =3.72, *p*=.09, n_{p2}=.32 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=0.58, *p*=.64, n_{p2}=.18 nor congruency and gender, *F*(1,8)=0.03, *p*=.18, n_{p2}=.21 was present.

The three-way interaction between brightness, congruency and order group, *F*(3,8) =0.58, *p*=.64, n_{p2}=.18 and between brightness, congruency and gender, *F*(1,8)=0.03, *p*=.87, n_{p2}=.01, brightness, order group and gender, *F*(3,8)=0.37, *p*=.78, n_{p2}=.12, congruency, order group and gender, *F*(3,8)=1.82, *p*=.22, n_{p2}=.41 were not significant. The four-way interaction between brightness, congruency, order group and gender, *F*(3,8)=2.51, *p*=.13, n_{p2}=.48 was not significant.

4.6.3 Post-collision looking time for test events

4.6.3.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.13, *p*=.73, n_{p2}=.02. Analysis revealed no significant main effect for brightness, *F*(1,8)=0.04, *p*=.84, n_{p2}=.01. The interaction between brightness and congruency was significant, *F*(1,8)=12.51, *p*<.01, n_{p2}=.61.

Infants looked significantly (*p*=.04) longer at the dark ball congruent test event (*M*=0.46) compared to the dark ball incongruent test event (*M*=0.23). Moreover, infants looked significantly (*p*=.02) longer at the bright ball incongruent test event (*M*=0.45) compared to the bright ball congruent test event (*M*=0.26). These are an effect of travel distance with a preference for the longer distance.

4.6.3.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=3.69, *p*=.06 n$_{p2}$=.58 nor for gender, *F*(1,8)=0.36, *p*=.56, n$_{p2}$=.04 was demonstrated. Similarly, the interaction between order group and gender was not significant, *F*(3,8)=0.33, *p*=.81, n$_{p2}$=.11. No interaction effect for brightness and order group, *F*(3,8)=0.10, *p*=.96, n$_{p2}$=.04 nor brightness and gender, *F*(1,8) =0.73, *p*=.42, n$_{p2}$=.08 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=0.11, *p*=.95, n$_{p2}$=.04 nor congruency and gender, *F*(1,8)=0.31, *p*=.60, n$_{p2}$=.04 was present.

The three-way interaction between brightness, congruency and order group, *F*(3,8) =0.64, *p*=.61, n$_{p2}$=.19 and between brightness, congruency and gender, *F*(1,8)=3.27, *p*=.11, n$_{p2}$=.29, brightness, order group and gender, *F*(3,8)=0.51, *p*=.69, n$_{p2}$=.16, congruency, order group and gender, *F*(3,8)=1.03, *p*=.43, n$_{p2}$=.28 were not significant. The four-way interaction between brightness, congruency, order group and gender, *F*(3,8)=2.99, *p*=.10, n$_{p2}$=.53 was not significant.

4.7 Experiment 5: Explanation of findings

Results from post-collision looking time analysis suggest that there is an effect of travel distance with a preference for the longer distance. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. Besides these findings, the results obtained from Experiment 5 do not support our hypothesis that suggested infants would display longer looking times at incongruent test events compared to congruent test events.

The results produced from 6 to 7 month old infants in Experiment 5 suggest that infants between 6 and 7 months of age fail to perceive the mass cues of object brightness in the collision events contrary to our hypothesis.

Experiment 6: Infants’ perception of object size and brightness in collision events

Experiment 6 assessed infants' perception of collision events based on both size and brightness of agent objects in collision events similar to those in Experiment 4 and 5. However, size dimensions were like Experiment 4, and brightness of objects like Experiment 5. Two cues for mass was paired in this study; large dark and small bright. We hypothesised that incongruent test events (size+brightness-inappropriate distances) would be allocated longer looking time compared to congruent test events (size+brightness-appropriate distances). Incongruent test events were events in which a large dark ball propelled a cube a shorter distance and small bright ball propelled it a longer distance. Similarly, congruent test events were events in which a large dark ball propelled a cube to longer distance and small bright ball propelled it a shorter distance.

4.8 Experiment 6: Methods

4.8.1 Participants

A total of 51 participants took part in the experiment, but due to failure to habituate (*N*=21) and successful habituation but failure to watch the test events after collision took (*N*=14), the final sample consisted of 16 participants. The 16 participants were between ages 182 days to 204 days (*M*=190.44, *SD*=6.27). All participants were recruited from the database at Lancaster University Baby-lab. Participants were healthy, full-term infants and received a book for their participation alongside being reimbursed for travelling costs. Of these 16 infants, 7 were female (*M*=188.71, *SD*=5.41) and 9 were male (*M*=191.78, *SD*=6.87).

4.8.2 Materials and apparatus

Materials and apparatus were identical to Experiment 5, apart from the fact that the balls followed the dimensions of Experiment 4 (see Fig 4.6). In that black ball was large and the white ball was small.

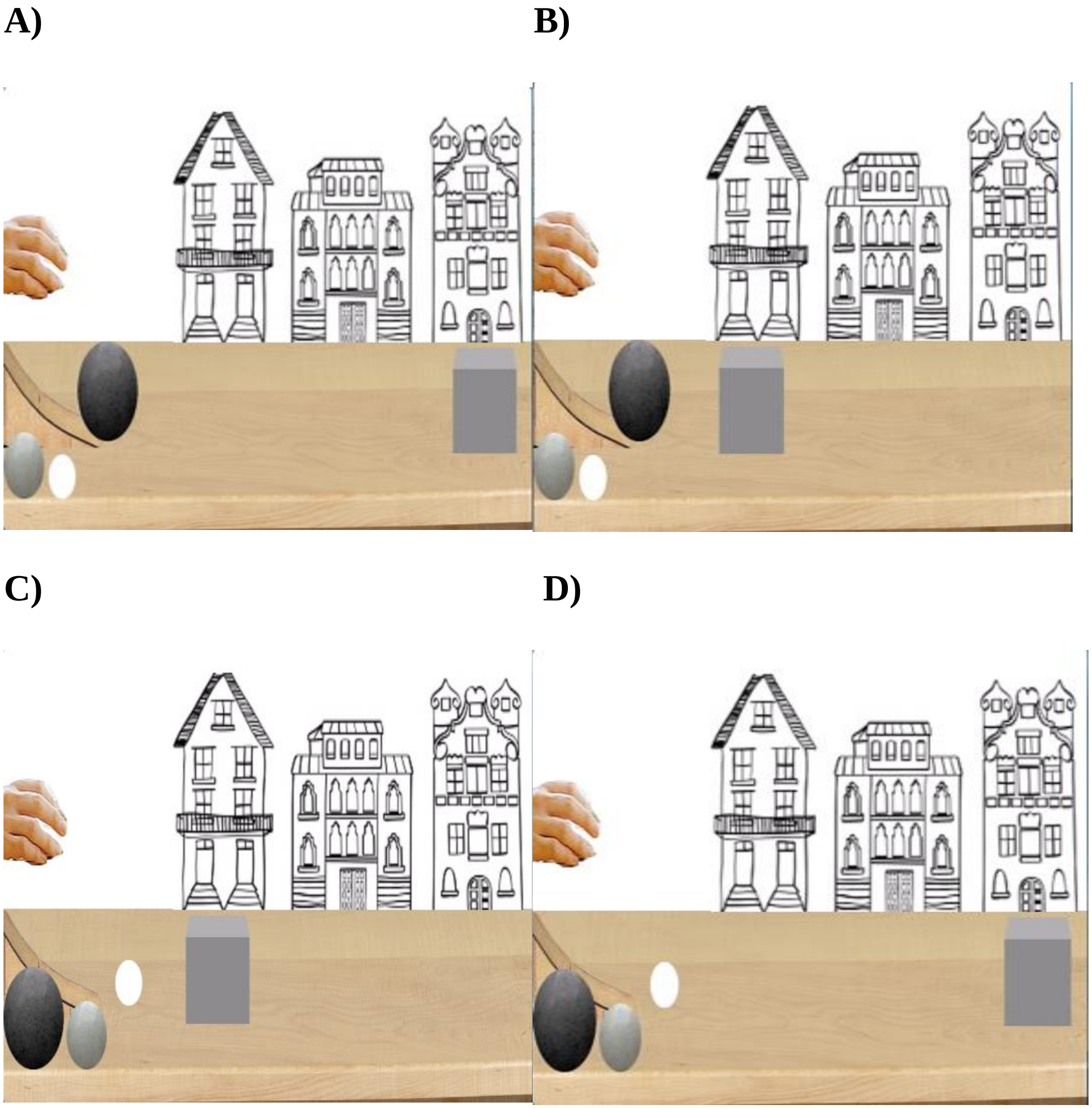


Fig 4.6. From top to bottom: Top: (A) Large dark congruent, (B) Large dark incongruent, Bottom: (C) Small bright congruent, (D) Small bright incongruent event.

4.8.3 Procedure

The procedure was identical to that of Experiment 5.

4.9 Experiment 6: Results

Total looking time and looking time post-collision were the parameters extracted for test events. Total looking time is the time the infant spent looking at the entire test event. Post-collision looking time is the time the infant spent looking from the collision between agent and patient object onwards till the start of the next loop. Total looking time and looking time post-collision were analysed with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with size+brightness (large dark or small bright) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

4.9.1 Test events

The total and post-collision looking time data for test events were not normally distributed thus a log transformation was performed prior to analyses. The raw total and post-collision looking time data for test events is reported in Fig 4.7 and Fig 4.8.

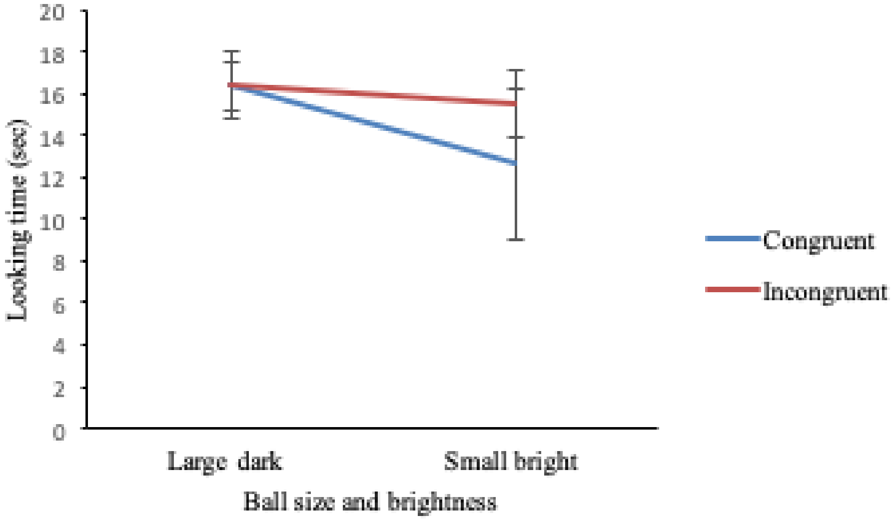


Fig 4.7. Raw mean total looking time for large dark and small bright ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

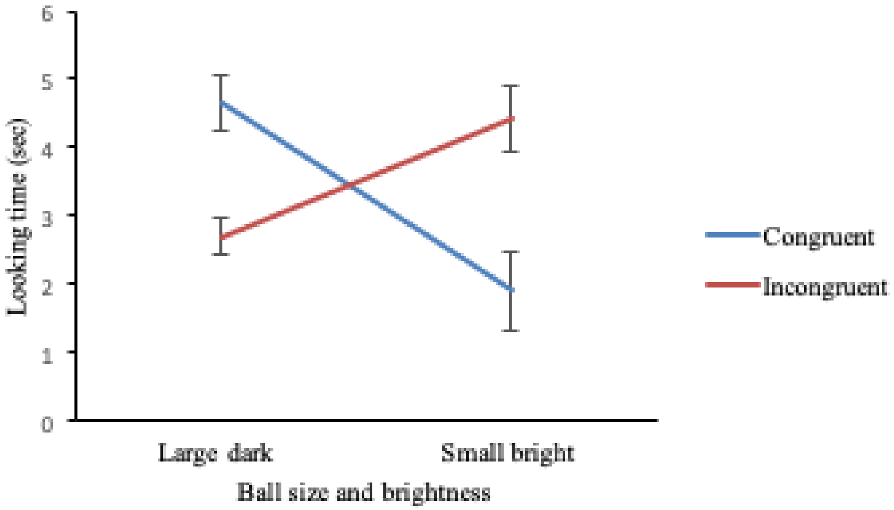


Fig 4.8. Raw mean post-collision looking time for large dark and small bright ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

4.9.2 Total looking time for test events

4.9.2.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.67, *p*=.44, n_{p2}=.08. Infants did not differ in their looking time for congruent and incongruent test events. Analysis revealed no significant main effect for size+brightness, *F*(1,8)=0.35, *p*=.57, n_{p2}=.04. The interaction between size+brightness and congruency was not significant, *F*(1,8)=0.69, *p*=.43, n_{p2}=.08.

4.9.2.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=0.89, *p*=.49, n_{p2}=.25 nor for gender, *F*(1,8)=0.12, *p*=.74, n_{p2}=.02 was demonstrated. Similarly, the interaction between order group and gender was not significant, *F*(3,8)=0.73, *p*=.56, n_{p2}=.22. No interaction effect for size+brightness and order group, *F*(3,8)=1.24, *p*=.36, n_{p2}=.32 nor size+brightness and gender, *F*(1,8)=0.54, *p*=.48, n_{p2}=.06 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=0.96, *p*=.46, n_{p2}=.26 nor congruency and gender, *F*(1,8)<0.001, *p*=.99, n_{p2}=.01 was present.

The three-way interaction between size+brightness, congruency and order group, *F*(3,8)=2.38, *p*=.15, n_{p2}=.47 and between size+brightness, congruency and gender, *F*(1,8)=0.11, *p*=.75, n_{p2}=.01, size+brightness, order group and gender, *F*(3,8)=1.89, *p*=.21, n_{p2}=.41, congruency, order group and gender, *F*(3,8)=0.99, *p*=.45, n_{p2}=.27 were not significant. The four-way interaction between size+brightness, congruency, order group and gender, *F*(3,8)=0.97, *p*=.45, n_{p2}=.27 was not significant.

4.9.3 Post-collision looking time for test events

4.9.3.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=1.83, *p*=.21, n$_{p2}$=.19. Analysis revealed no significant main effect for size+brightness, *F*(1,8)=0.44, *p*=.53, n$_{p2}$=.05.The interaction between size+brightness and congruency was significant, *F*(1,8) =34.69, *p*<.001, n$_{p2}$=.81. Infants looked significantly (*p*=.01) longer at the large dark ball congruent event (*M*=0.58) compared to large dark ball incongruent event (*M*=0.37). Infants looked significantly (*p*<.001) longer at the small bright ball incongruent event (*M*=0.57) compared to the small bright ball congruent event (*M*=0.19). These are an effect of travel distance with a preference for the longer distance.

4.9.3.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=1.74, *p*=.24, n$_{p2}$=.40 nor for gender, *F*(1,8)=0.10, *p*=.76, n$_{p2}$=.01 was demonstrated. Similarly, the interaction between order group and gender was not significant, *F*(3,8)=2.88, *p*=.10, n$_{p2}$=.52. No interaction effect for size+brightness and order group, *F*(3,8)=0.55, *p*=.66, n$_{p2}$=.17 nor size+brightness and gender, *F*(1,8)=0.59, *p*=.47, n$_{p2}$=.07 existed. Similarly, no interaction effect for congruency and order group, *F*(3,8)=0.72, *p*=.57, n$_{p2}$=.21 nor congruency and gender, *F*(1,8)=0.14, *p*=.72, n$_{p2}$=.06 was present.

The three-way interaction between size+brightness, congruency and order group, *F*(3,8)=3.01, *p*=.10, n$_{p2}$=.53 and between size+brightness, congruency and gender, *F*(1,8)=0.22, *p*=.65, n$_{p2}$=.03, size+brightness, order group and gender, *F*(3,8)=1.36, *p*=.32, n$_{p2}$=.34, congruency, order group and gender, *F*(3,8)=0.91, *p*=.48, n$_{p2}$=.25 were not significant. The four-way interaction between size+brightness, congruency, order group and gender, *F*(3,8)=0.84, *p*=.51, n_{p2}=.24 was not significant.

4.10 Experiment 6: Explanation of findings

Results from post-collision looking time analysis suggest that there is an effect of travel distance with a preference for the longer distance. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. Besides these findings, the results obtained from Experiment 6 do not support our hypothesis that suggested infants would display longer looking times at incongruent test events compared to congruent test events.

The results produced from 6 to 7 month old infants in Experiment 6 suggest that infants between 6 and 7 months of age fail to perceive the mass cues of object size+brightness in the collision events contrary to our hypothesis.

4.11 Analysis of all three experiments

Results of experiments described in this chapter were combined to test the effect of a larger sample on the experimental findings. All experiments had an object that cued less mass and an object that cued more mass. Similarly, the test events were either congruent or incongruent (congruency). These data were analysed with GLM repeated measures with experimental group (Experiment 4,5 and 6) as between-subjects factor, and mass (less or more mass) and congruency (congruent or incongruent) as within-subjects factor.

4.11.1. Total looking time for test events for experiments 4,5 and 6

4.11.1.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,45)=0.02, *p*=.89, n_{p2}=.01. As displayed in Fig 4.9, infants did not differ in their looking times for the congruent and incongruent test events. Analysis revealed a significant main effect for mass cues, *F*(1,45)=7.30, *p*=.01, n_{p2}=.14. Infants looked longer at objects of more mass (*M*=1.08) compared to objects of less mass (*M*=1.02). The interaction between mass cues and congruency was not significant, *F*(1,45)=1.04, *p*=.31, n_{p2}=.02.

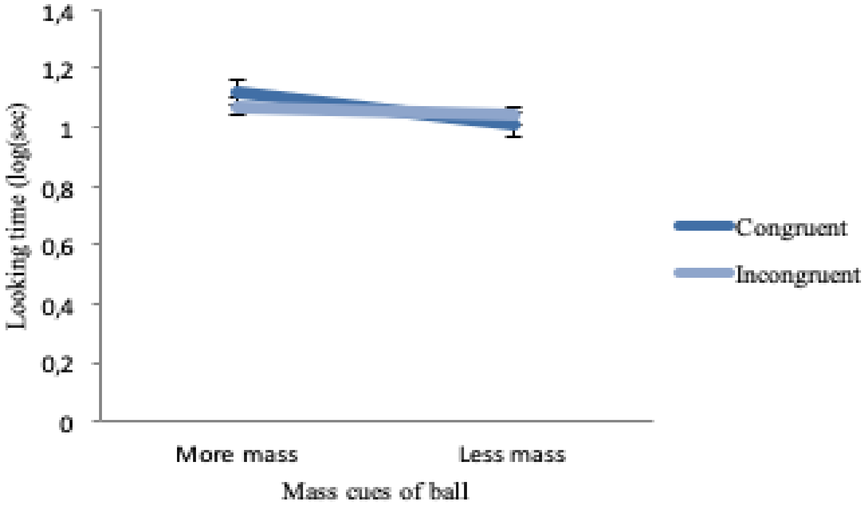


Fig 4.9. Log transformed mean total looking time for congruent and incongruent test events based on more mass and less mass cues of ball. Data are presented as mean looking time and standard error of mean.

4.11.1.2 Secondary analysis

No significant main effect for experiment, *F*(2,45)=1.36, *p*=.27, n_{p2}=.06. There was no significant interaction between mass cues and experiment, *F*(2,45)=2.89, *p*=.07, n_{p2}=.11 and between congruency and experiment, *F*(2,45)=0.99, *p*=.38, n_{p2}=.04. The three-way interaction between mass cues, congruency and experiment was not significant, *F*(2,45)=1.09, *p*=.35, n_{p2}=.05.

4.12 Chapter 4 discussion

Results from experiments conducted in Chapter 4 suggest that infants fail to perceive the mass cues of object size, object brightness, and size+brightness in the collision events contrary to our hypothesis. Post-collision analyses for all experiments in this chapter suggest that infants have a distance preference for longer distances. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. This could be explained by the longer duration of these animations. The animations were longer for the events in which the cube was propelled to the endpoint of the screen compared to the events in which the cube was propelled before the midpoint of the screen. The analysis of the pooled results for Experiments 4, 5 and 6 can be interpreted as showing that infants were indeed sensitive to the differences in cues that indicate mass such as size and brightness, but just didn’t use them when presented with collision events.

Experiments outlined in Chapter 4 introduced an alternative methodology to Kotovsky and Baillargeon’s (1998) version of collision events as outlined in Chapter 1, to examine infants' expectations about object properties; size, brightness, and size+brightness in collision events. Results concerning object size in collision events did not produce results in line with Kotovsky and Baillargeon’s (1998) findings. The object property brightness, and size+brightness studied herein are novel as these have not been tested in collision events with infants prior to this thesis. For that reason, findings concerning object brightness and size+brightness can be attributed differently than the study findings for size.

Previous experiments that have investigated size in collision events have found a difference in looking time between the large and small ball events when the toy-bug is propelled to the endpoint of the screen (Kotovsky & Baillargeon, 1994; 1998). In these experiments, both 5.5 to 6.5 and 10 to 11 month old infants looked longer at the small ball test event compared to the large ball test event. This suggests that infants find the small ball test event to violate the expectation. 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 patient object to shorter distance. On the assumption that infants use size to infer mass in collision events as concluded by Kotovsky and Baillargeon (1998), infants should be able to discriminate between object sizes in the shorter distance condition similarly to the longer distance condition as found in their experiment. Based on this assumption, infants should have looked longer at the event in which a large ball propels a patient object to a shorter distance compared to a small ball displaying the same behaviour. Instead, we found infants looked longer at large ball test events compared to small ball events irrespective of congruency.

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 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 (Newman et al., 2001). 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 (Newman et al., 2001). This can be explained by the more prominent details of a larger object (Libertus et al., 2013).

The experiments of Kotovsky and Baillargeon (1994; 1998) were conducted with 3D real-life objects as opposed to 3D computer-generated collision events like our experiments. However, Hohenberger et al. (2012) were successful with their replication of Kotovsky and Baillargeon (1994; 1998) experiments with 10 month old infants using animation. Hohenberger et al. (2012) were successful with 10-month-olds but not 6-month-olds despite the agent object rolled down the ramp on its own without an external force as a hand was not present to set objects in motion (Hohenberger et al., 2012). In our experiments we controlled for this by inserting a picture of a hand that manipulated the objects and set them into motion. Hohenberger and colleagues (2012) successful replication with 10-month-olds but not 6-month-olds suggest that nature of their animations might have been the restricting factor.

Several experiments suggest that infants behave differently when shown animate object characterised by their self-propelling nature and inanimate objects (real-objects), infants fail to understand the violation of expectation when viewing animate objects (Gergely, Nadasdy, Csibra, & Biro, 1995; Rochat, Morgan, & Carpenter, 1997; Shimizu, & Johnson, 2004; Luo, & Baillargeon, 2005; Schlottman, & Ray, 2010; Poulin-Dubois, Lepage, & Ferland, 1996;Saxe, Tenenbaum, & Carey, 2005;Markson, & Spelke, 2006; Pauen, & Träuble,2009). Nevertheless, this suggestion has been challenged in recent years by various authors who have been successful with using animate (self-propelled) objects (Mascalzoni, Regolin, Vallortigare, & Simion, 2013). Infants as young as 8 hours to 71 hours have demonstrated a preference for causal events over non-causal with the use of self-propelled objects (Mascalzoni, Regolin, Vallortigare, & Simion, 2013).

The experiment examining object brightness in collision events in this thesis was conducted based on past research that suggests a link between object brightness and weight (Plack & Shick, 1976; Haryu & Kajikawa, 2012). Object brightness has been demonstrated to affect pre-schooled children's judgement of object weight (Plack & Shick, 1976). Pre-school children judge darker colours to be heavier in weight and brighter colours to be lighter in weight (Plack & Shick, 1976). Similarly, infants associate darker colours with low pitch sounds, and brighter colours with high pitch sounds (Haryu & Kajikawa, 2012). Darker colours and low pitch sounds cue heavy weight and brighter colours and high pitch sounds cue light weight in adults (Walker, 2012). However, our results were not in line with these past findings. Similarly, the two cues (size and brightness) produced findings that suggested that infants did not perceive the mass cues of object size and brightness in our collision events.

Limitations

The results of Chapter 4 suggest that the task of perceiving object mass cues in the collision events might have been ambiguous or complex for an infant audience. There are a number of variables that infants need to perceive such as a) object properties 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 properties and their cues to mass in collision events might require advanced perceptual reasoning that is beyond infants in this age range.

Conclusion

The findings in Chapter 4 indicate that these experiments fail to provide evidence that infants perceive mass cues of object properties size, brightness, and size and brightness in collision events.

Chapter 5 – Infants use of object size as a cue to mass in collision events

Abstract

It is claimed that infants perceive the size of an agent object in collision events from about 5.5 to 6.5 months of age (Kotovsky, & Baillargeon, 1998). Infants perceive a patient object to be propelled further followed by a collision with a large agent object compared to a small agent object (Kotovsky & Baillargeon, 1994; 1998). This relationship is detected when the agent object is varied in size but the patient object is kept constant in size (Kotovsky & Baillargeon, 1998). It is uncertain whether infants use size in collision events when the agent object is kept constant in size and the patient object is varied in size. Particularly, whether infants perceive a small patient object to be displaced further than a large patient object following a collision with a mid-size agent object. The present experiments examined 10-11 month old infants' use of size of agent object (Experiment 7), and size of patient object (Experiment 8) by keeping the other object constant in size using 3D computer-generated collision events. The results from this chapter indicate that these experiments fail to provide evidence that infants consider mass cues of object size of agent and patient object in collision events.

5.1 Introduction

Some authors posit that infants perceive a collision between an agent and patient object based on force of agent object (Chinta, 2014; Leslie, 1995). Furthermore, this force perception of agent object is claimed to help infants in their perception of smaller and larger agent objects involved in physical events (Leslie, 1995; Leslie & Keeble, 1987). Particularly, that larger objects in relation to smaller objects are more likely to exert greater force and result in greater displacements of a patient object (Leslie, 1995; Spelke, Phillips, & Woodward, 1995). For example, infants of 5.5-6.5 month of age perceive a larger agent object to propel a patient object to a longer distance than a smaller agent object (Kotovsky, & Baillargeon, 1998).

This force perception of the agent object has also been demonstrated to help infants detect the direction of collision events (Leslie & Keeble, 1987; Oakes, 1994; Oakes & Cohen, 1990). For example, infants are able to perceive the reversal of the collision events e.g. when the patient object causes the agent object to move in the opposite direction by 6 months of age (Leslie & Keeble, 1987; Oakes, 1994; Oakes & Cohen, 1990). This perception suggests that infants perceive the agent object to set the patient object into motion through the force perception of the agent object (Leslie & Keeble, 1987). Yet, there are a paucity of data concerning infants' perception of force in collision events.

One such paucity of data concerns how infants respond to events in which the same force is exerted by the agent object to a patient objects of varying sizes. Infants perception of force of smaller and larger objects in collision events can solely been attributed to the size of the agent object (Kotovsky & Baillargeon, 1998). The size of the patient object has not been considered in the infant literature to my knowledge. The scope of this chapter is therefore to investigate infants' use of size of the patient object as a cue for mass in collision events.

Size cues for mass with the assumption that larger objects are often heavier in weight than smaller objects (Woodworth, 1921). For that reason, it makes sense that heavier objects exert greater force and move other objects further regardless of direction (Kotovsky & Baillargeon, 1998; Woodworth, 1921). However, this assumption is not true in cases when the agent object is constant in size and the patient object varies in size. In these cases, the force exerted by the agent object is the same. Infants should therefore infer the outcome of the collision event based on the size differences of patient objects. In other words, infants should expect a patient object of small size to be propelled further than a patient object of large size by the mid-size agent object.

In Kotovsky and Baillargeon's (1998) experiment, infants demonstrate the ability to perceive the size of agent object on the propelled distance of the stationary object. For that reason, it makes sense to test whether infants can transfer this ability to infer size of the agent object to infer size of the patient object and expect certain outcomes of collision events based on the size of the agent and the patient object. In our experiments, we used the experimental setup by Kotovsky and Baillargeon (1998) with some changes as detailed in Chapter 2 (General methods). We first tested a group of 10 to 11-month old infants on the size of the agent object in the collision events. This experiment was identical to Experiment 4 in Chapter 4. Next, we tested another group of 10 to 11-month old infants on the size of the patient object in the collision events. Infants in this experiment were first habituated to an event in which a mid-size billiard ball rolled down a ramp and propelled a mid-size cube to the midpoint of the screen. Next, infants saw a mid-size billiard ball roll down a ramp and propel either a large or small-size cube to before midpoint or endpoint of the screen.

It was hypothesized that infants in both experiments will display longer looking times at events that violate the expectations of the size appropriate distances. Infants should expect a mid-size agent object to exert the same force on a small patient object as a large patient object. As a result of infants’ expectations, the propelled distance of the patient object should be attributed to the size differences of the patient object. The event in which the small patient object is propelled to longer distance by a mid-size agent object compared to shorter distance would be more likely assumed by the infants. Similarly, the event in which the large patient object is propelled to a shorter distance by a mid-size agent object compared to longer distance would more readily be assumed. In the looking time paradigm this would mean that infants would look longer at the events that violated expectations, thus those that are the opposite to the assumptions they hold. The opposite to the assumptions would be a mid-size agent object propels a large patient object to long distance or a small patient object to a shorter distance.

The findings from this chapter can yield a valuable insight about infants’ use of size and force relationships in collision events (Kotovsky & Baillargeon, 1998). The present investigations can also answer the magnitude of the perceptual skills of the 10-to-11-month-old infants.

Experiment 7: Infants’ use of size of agent object in collision events

Experiment 7 examined infants' use size of agent object in collision events similar to the infant Experiment 4 in Chapter 4. We hypothesized that infants will display longer looking times at events that are incongruent (size-inappropriate distances) compared to congruent events (size-appropriate distances). Incongruent events are events in which either a large ball propels a patient object to a shorter distance or a small ball propels a patient object to a longer distance. Conversely, congruent events are events in which either a large ball propels a patient object to a longer distance or a small ball propels a patient object to a shorter distance.

5.2 Experiment 7: Methods

5.2.1 Participants

A total of 32 participants took part in the experiment, but due to equipment failure (*N*=1), failure to habituate (*N*=12) and successful habituation but failure to watch the test events after collision took (*N*=3), the final sample consisted of 16 participants. The 16 participants were between ages 304 days to 335 days (*M*=321.38, *SD*=10.94). All 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 travelling costs. Of these 16 infants, 8 were female (*M*=320.13, *SD*=12.36) and 8 were male (*M*=322.63, *SD*=10.00).

5.2.2 Materials and apparatus

Materials and apparatus were alike to Experiment 4 in Chapter 4.

5.2.3 Procedure

Procedure was identically to Experiment 4.

5.3 Experiment 7: Results

Total looking time and looking time post-collision were the parameters extracted for test events. Total looking time is the time the infant spent looking at the entire test event. Post-collision looking time is the time the infant spent looking from the collision between agent and patient object onwards till the start of the next loop. Total looking time and looking time post-collision were analysed with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with size (large or small) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

5.3.1 Test events

The total and post-collision looking time data for test events were not normally distributed thus a log transformation was performed prior to analyses. The raw total and post-collision looking time data for test events is reported in Fig 5.1 and Fig 5.2.

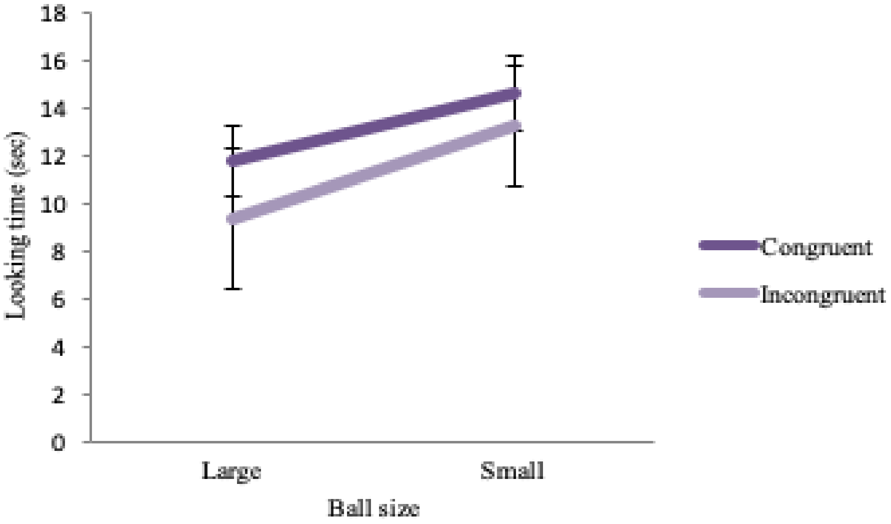


Fig 5.1. Raw mean total looking time for large and small ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

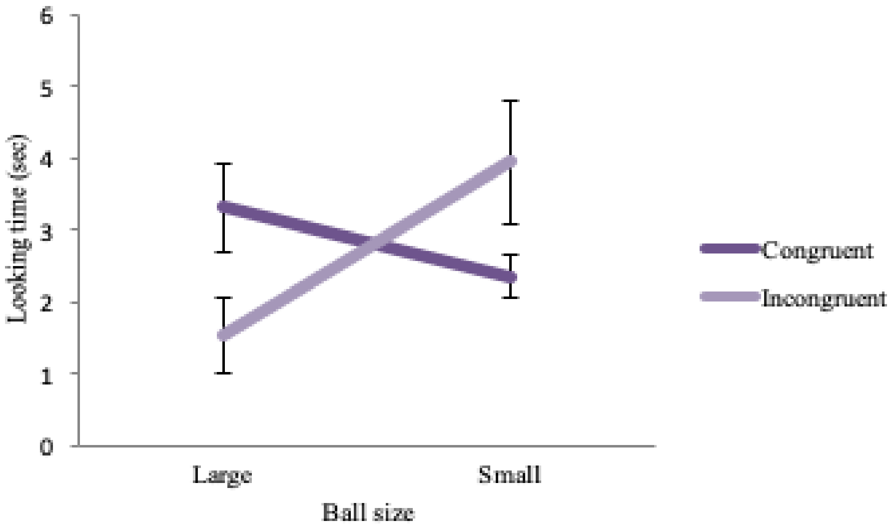


Fig 5.2. Raw mean post-collision looking time for large and small ball congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

5.3.2 Total looking time for test events

5.3.2.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=3.13, *p*=.12, n_{p2}=.28. Infants did not differentiate in their looking time for congruent and incongruent test events. Analysis revealed no significant main effect for size *F*(1,8)=1.15, *p*=.31, n_{p2}=.13.The interaction between size and congruency was not significant, *F*(1,8)=0.59, *p*=.47, n_{p2}=.07.

5.3.2.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=1.50, *p*=.29, n_{p2}=.36 nor for gender, *F*(1,8)=1.13, *p*=.32, n_{p2}=.32 was exposed. The interaction between order group and gender was not significant, *F*(3,8)=0.79, *p*=.53, n_{p2}=.23. No interaction effect for size and order group, *F*(3,8)=0.87, *p*=.50, n_{p2}=.25 nor size and gender, *F*(1,8)=0.01, *p*=.94, n_{p2}=.01 existed. Similarly, no interaction effect for congruency and order group, $F(3,8)=1.00$, $p=.44$, $n_{p2}=.27$ nor congruency and gender, $F(1,8)=0.17$, $p=.69$, $n_{p2}=.02$ was demonstrated.

The three-way interaction between size, congruency and order group, $F(3,8)=1.30$, $p=.34$, $n_{p2}=.33$ and between size, order group and gender, $F(3,8)=0.51$, $p=.69$, $n_{p2}=.16$, congruency, order group and gender, $F(3,8) =0.72$, $p=.57$, $n_{p2}=.21$ were not significant. The three-way interaction between size, congruency and gender, $F(1,8)=7.62$, $p=.03$, $n_{p2}=.49$ was significant. This finding suggest that female infants looked significantly ($p=.05$) longer at large ball congruent event ($M=1.04$) compared to large ball incongruent event ($M=0.90$). The four-way interaction between size, congruency, order group and gender, $F(3,8)=0.68$, $p=.59$, $n_{p2}=.20$ was not significant.

5.3.3 Post-collision looking time for test events

5.3.3.1 Primary analysis

Analysis revealed no significant main effect for congruency, $F(1,8)=0.74$, $p=.41$, $n_{p2}=.09$. Analysis revealed no main effect for size, $F(1,8)=1.76$, $p=.22$, $n_{p2}=.18$.The interaction between size and congruency was significant, $F(1,8)=24.34$, $p<.001$, $n_{p2}=.75$. Infants looked significantly ($p<.001$) longer at the large ball congruent test event ($M=0.45$) compared to the large ball incongruent test event ($M=0.11$). Infants looked significantly ($p=.01$) longer at the small ball incongruent test event ($M=0.50$) compared to the small ball congruent test event ($M=0.24$). These are an effect of travel distance with a preference for the longer distance.

5.3.3.2 Secondary analysis

No significant main effect for order group, $F(3,8)=1.19$, $p=.38$, $n_{p2}=.31$ nor for gender, $F(1,8)=0.98$, $p=.35$, $n_{p2}=.11$ was exposed. The interaction between order group and gender was not significant, $F(3,8)=0.28$, $p=.84$, $n_{p2}=.10$. No significant interaction effect for size and order group, *F*(3,8)=1.57, *p*=.27, n_{p2}=.37 nor for size and gender, *F*(1,8)=0.39, *p*=.55, n_{p2}=.05 existed. Similarly, no significant interaction effect for congruency and order group, *F*(3,8)=1.17, *p*=.38, n_{p2}=.31 nor congruency and gender, *F*(3,8)=1.97, *p*=.20, n_{p2}=.20 was demonstrated.

The three-way interaction between size, congruency and order group, *F*(3,8)=0.91, *p*=.48, n_{p2}=.26 and between size, congruency and gender, *F*(1,8)=2.96, *p*=.12, n_{p2}=.27, size, order group and gender, *F*(3,8)=0.47, *p*=.71, n_{p2}=.15, congruency, order group and gender, *F*(3,8) =0.85, *p*=.50, n_{p2}=.24 were not significant. The four-way interaction between size, congruency, order group and gender, *F*(3,8)=0.80, *p*=.53, n_{p2}=.23 was not significant.

5.4 Experiment 7: Explanation of findings

Results from post-collision looking time analysis suggest that there is an effect of travel distance with a preference for the longer distance. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. Besides these findings, the results obtained from Experiment 7 do not support our hypothesis that suggested infants would display longer looking times at incongruent test events compared to congruent test events.

The results produced from 10 to 11 month old infants in Experiment 7 suggest that infants between 10 and 11 months of age fail to consider the mass cues of agent object size in the collision events contrary to our hypothesis.

Experiment 8: Infants’ perception of size of patient object in collision events

Experiment 8 examined infants' anticipation of collision events based on size of patient object. We hypothesized that infants will display longer looking times at events that are incongruent (size-inappropriate distances) compared to congruent events (size-appropriate distances). Incongruent events are events in which either a mid-size ball propels a large patient object to a longer distance or a small patient object to a shorter distance. Conversely, congruent events are events in which either a large patient object is propelled to shorter distance and small patient object is propelled to a longer distance by a mid-size ball.

5.5 Experiment 8: Methods

5.5.1 Participants

A total of 31 participants took part in the experiment, but due to failure to habituate (*N*=4) and successful habituation but failure to watch the test events after collision took (*N*=11), the final sample consisted of 16 participants. The 16 participants were between ages 304 days to 333 days (*M*=318.81, *SD*=10.68). All 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 travelling costs. Of these 16 infants, 7 were female (*M*=312.29, *SD*=8.58) and 9 were male (*M*=323.89, *SD*=9.61).

5.5.2 Materials and apparatus

Animations were alike Experiment 7 with some minor changes. The ball was the same size as the mid-size ball in Experiment 7 (*H*=60 px, *W*=60 px), and the cube differed in size (small, mid-size and large). During habituation events the cube was mid-size (*H*=60 px, *W*=60 px), but was small (*H*=40 px, *W*=40 px) or large (*H*=90 px, *W*=90 px) size during test events (see Fig 5.3).

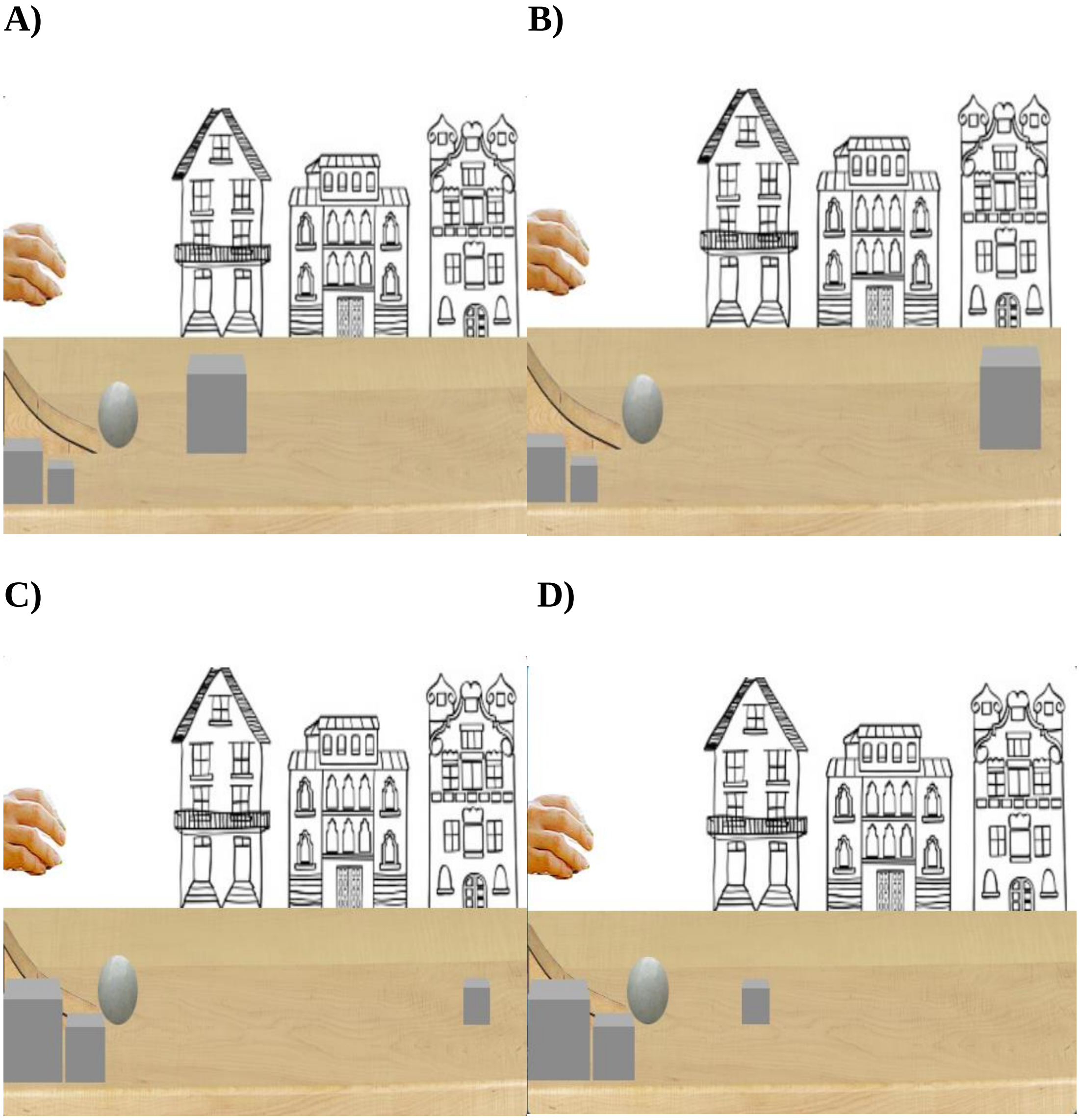


Fig 5.3. From top to bottom: Top: (A) Large cube congruent, (B) Large cube incongruent, Bottom: (C) Small cube congruent, (D) Small cube incongruent event.

5.5.3 Procedure

The procedure was identical to Experiment 7. However, the congruent and incongruent events for the test events differed from Experiment 7 (see Fig 5.3). Infants in this experiment were subdivided into following groups and viewed the events shown on Fig 5.3 in following sequences:

Group one: A-B-C-D

Group two: B-A-D-C

Group three: C-D-A-B

Group four: D-C-B-A

5.6 Experiment 8: Results

Total looking time and looking time post-collision were the parameters extracted for test events. Total looking time is the time the infant spent looking at the entire test event. Post-collision looking time is the time the infant spent looking from the collision between agent and patient object onwards till the start of the next loop. Total looking time and looking time post-collision were analysed with general linear model repeated measures with order (1, 2, 3 or 4) and gender as a between-subjects factor and with size (large or small) and congruency (congruent or incongruent) as within-subjects factors. We investigated the main effect of congruency. Where an effect was present subsequent paired sample t-tests with Bonferroni corrections were performed.

5.6.1 Test events

The total and post-collision looking time data for test events were not normally distributed thus a log transformation was performed prior to analyses. The raw total and post-collision looking time data for test events is reported in Fig 5.4 and Fig 5.5.

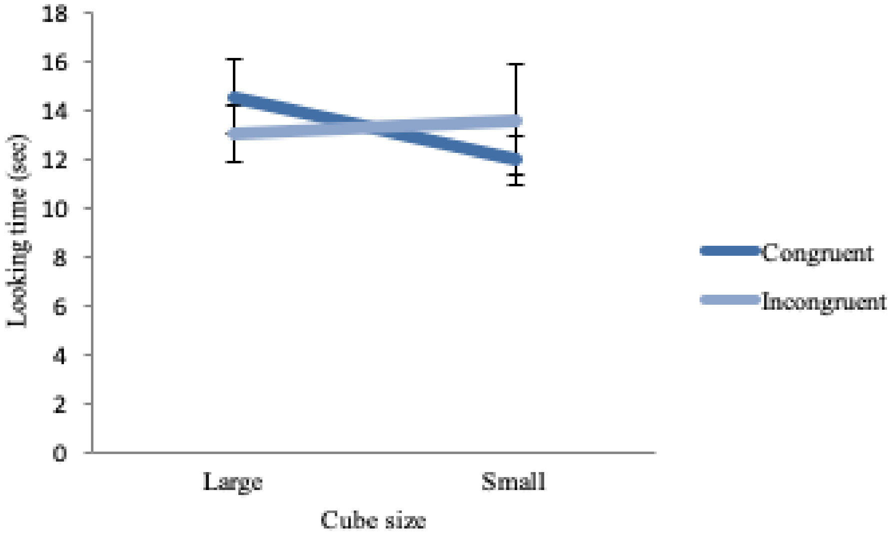


Fig 5.4. Raw mean total looking time for large and small cube congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

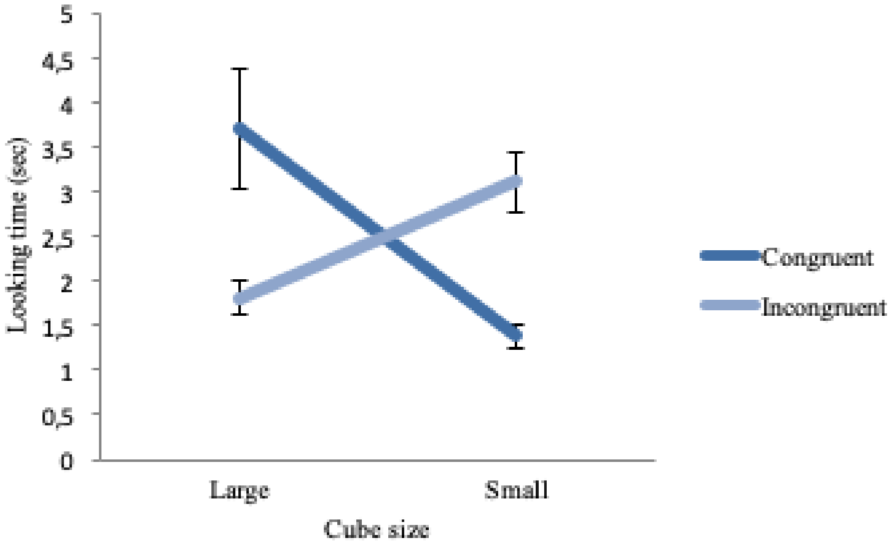


Fig 5.5. Raw mean post-collision looking time for large and small cube congruent and incongruent test events. Data are presented as mean looking time and standard error of mean.

5.6.2 Total looking time for test events

5.6.2.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.10, *p*=.76, n_{p2}=.01. Infants display no looking time differences between congruent and incongruent test event. Analysis revealed no significant main effect for size, *F*(1,8)=0.82, *p*=.39, n_{p2}=.09. The interaction between size and congruency was not significant, *F*(1,8)=0.51, *p*=.49, n_{p2}=.06.

5.6.2.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=3.05, *p*=.09, n_{p2}=.53 nor for gender, *F*(1,8)=0.64, *p*=.45, n_{p2}=.07 was exposed. The interaction between order group and gender was not significant, *F*(3,8)=2.09, *p*=.18, n_{p2}=.44. No interaction effect for size and order group, *F*(3,8)=1.53, *p*=.28, n_{p2}=.36 nor for size and gender, *F*(1,8)=0.26, *p*=.62, n_{p2}=.03 existed. There was no significant interaction effect for congruency and order group, *F*(3,8)=0.37, *p*=.78, n_{p2}=.12 nor for congruency and gender, *F*(1,8)=0.11, *p*=.65, n_{p2}=.03.

The three-way interaction between size, congruency and order group, *F*(3,8)=2.63, *p*=.12, n_{p2}=.50 and between size, order group and gender, *F*(3,8)=1.60, *p*=.26, n_{p2}=.38, congruency, order group and gender, *F*(3,8)=2.43, *p*=.14, n_{p2}=.48 were not significant. There was a significant three-way interaction for size, congruency and gender, *F*(1,8)=6.99, *p*=.03, n_{p2}=.47. Female infants looked significantly (*p*=.05) longer at the large cube congruent event (*M*=1.10) compared to large cube incongruent event (*M*=0.98). Male infants allocated significantly (*p*=.05) longer looking time to the large cube incongruent event (*M*=1.14) compared to the large cube congruent event (*M*=0.89). The four-way interaction between size, congruency, order group and gender, *F*(3,8)=0.303, *p*=.82, n_{p2}=.61 was not significant.

5.6.3 Post-collision looking time for test events

5.6.3.1 Primary analysis

Analysis revealed no significant main effect for congruency, *F*(1,8)=0.30, *p*=.60, n_{p2}=.04. Analysis revealed no significant main effect for size, *F*(1,8)=4.49, *p*=.07, n_{p2}=.36. The interaction between size and congruency was significant, *F*(1,8)=21.87, *p*<.01, n_{p2}=.73. Infants demonstrated significantly (*p*=.01) longer looking time at the large cube congruent test event (*M*=0.47) compared to the large cube incongruent test event (*M*=0.20). Infants looked significantly (*p*<.01) longer at the small cube incongruent test event (*M*=0.40) compared to the small cube congruent test event (*M*=0.09). These are an effect of travel distance with a preference for the shorter distance.

5.6.3.2 Secondary analysis

No significant main effect for order group, *F*(3,8)=1.10, *p*=.40, n_{p2}=.29 nor for gender, *F*(1,8)=0.03, *p*=.87, n_{p2}=.01 was exposed. The interaction between order group and gender was not significant, *F*(3,8)=0.78, *p*=.54, n_{p2}=.23. No significant interaction effect for size and order group, *F*(3,8)=3.62, *p*=.07, n_{p2}=.58 nor for size and gender, *F*(1,8)=0.24, *p*=.64, n_{p2}=.03 existed. There was no significant interaction effect for congruency and order group, *F*(3,8)=1.30, *p*=.34, n_{p2}=.33 nor for congruency and gender, *F*(1,8)=0.21, *p*=.66, n_{p2}=.04.

The three-way interaction between size, congruency and order group, *F*(3,8)=1.43, *p*=.30, n_{p2}=.35 and between size, order group and gender, *F*(3,8)=2.69, *p*=.12, n_{p2}=.50, congruency, order group and gender, *F*(3,8)=2.35, *p*=.13, n_{p2}=.46 were not significant. The three-way interaction for size, congruency and gender, *F*(1,8)=16.33, *p*<.01, n_{p2}=.67 was significant. Male infants looked significantly (*p*=.01) longer at the small cube incongruent test event (*M*=0.45) compared to small cube congruent test event (*M*=0.04). Female infants looked significantly

($p<.01$) longer at the large cube congruent test event (M=0.53) compared to the large cube incongruent test event (M=0.10). Moreover, female infants looked significantly ($p<.01$) longer at the small cube incongruent test event (M=0.35) compared to the small cube congruent test event (M=0.14). These results obtained with female infants are an effect of travel distance with a preference for the shorter distance. The four-way interaction between size, congruency, order group and gender, $F(3,8)=0.73$, $p=.56$, $n_{p2}=.22$ was not significant.

5.7 Experiment 8: Explanation of findings

Results from post-collision looking time analysis suggest that there is an effect of travel distance with a preference for the shorter distance. Infants looked longer at the events in which the cube was propelled to shorter distance compared to longer distance. Male infants demonstrated total looking time differences between congruent and incongruent test events for small cube in line with our hypothesis. Male infants looked longer at small cube incongruent test event in comparison to small cube congruent test event. Total looking time analyses demonstrated that male infants looked longer at large cube incongruent test event compared to large cube congruent test event in line with our hypothesis. Besides these findings, the results obtained from Experiment 8 do not support our hypothesis that suggested infants would display longer looking times at incongruent events compared to congruent events.

The results produced from 10 to 11 month old infants in Experiment 8 suggest that infants between 10 and 11 months of age fail to consider the mass cues of patient object size in the collision events contrary to our hypothesis.

5.8 Chapter 5 discussion

The findings of this chapter suggest that infants fail to consider the mass cues of size of agent and patient object in the collision events contrary to our hypothesis. Post-collision analyses for the Experiment 7 in this chapter suggest that infants have a distance preference for longer distances. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. This could be explained by the longer duration of these animations. The animations were longer for the events in which the cube was propelled to the endpoint of the screen compared to the events in which the cube was propelled before the midpoint of the screen. Post-collision analyses for the Experiment 8 suggest that infants have a distance preference for shorter distances. Infants looked longer at the events in which the cube was propelled to shorter distance compared to longer distance. Male infants display looking time differences between congruent and incongruent test events for small cube in line with our hypothesis. Male infants looked longer at small cube incongruent test event compared to small cube congruent test event. Furthermore, male infants display total looking time differences between congruent and incongruent test events for large cube in line with our hypothesis. Male infants looked longer at large cube incongruent test event compared to large cube congruent test event.

Experiments described in Chapter 5 present a first attempt to examine infants' use of size of both agent and patient objects in collision events. These experiments differ from the methodology of Kotovsky and Baillargeon (1998) but follow the similar principle to investigate size in collision events for the seventh experiment. The eighth experiment differs, because of the size manipulations of the patient object and the constant size of the agent object. Results of both experiments are contradictory to our hypothesis. This is demonstrated in infants' inability to distinguish between incongruent and congruent test events. Our hypothesis suggested that infants would display longer looking times to incongruent test events compared to congruent test events. However, the results obtained from the post-collision analysis for small cube and total-looking time analysis for large cube with male infants are in line with our hypothesis. Male infants looked longer at the small cube incongruent test event compared to small cube congruent test event.

Similarly, male infants looked longer at the large cube incongruent test event compared to the large cube congruent test event when data was analysed in total looking time.

Existing literature up to date, claim that 10-11 month old infants perceive object size in animated collision events (Hohenberger et al., 2012). These animated collisions are set into motion without an external force such as a hand. Our seventh experiment that is consistent with this experiment, and our eighth experiment have an agent in form of a hand that sets the objects in motion. These amendments have been implemented based on research that claim infants fail to perceive causality when events are self-propelled (Luo, Kaufman, & Baillargeon, 2009). Furthermore, we have included two more test events in which the patient object is propelled to a shorter distance. This has been implemented based on infants' ability to match the events in which the patient object is propelled to longer distance with the appropriate object size (Hohenberger et al., 2012). Infants match this mentioned event with the large size cylinder as opposed to small size cylinder (Hohenberger et al., 2012). Kotovsky and Baillargeon (1998) further argue that infants can match size of agent object with propelled distance of patient object. However, these findings are based on only one distance, endpoint of the screen (longer distance). For that reason, we have included a shorter distance (before the midpoint of the screen). Despite these amendments, we failed to produce similar findings in line with the results of Kotovsky and Baillargeon (1998), and Hohenberger et al. (2012).

Our eighth experiment is the first to examine 10 to 11 month old infants' use of size of the patient object in collision events. The size of the patient object in collision events have not been studied to my knowledge. Infants perception of the patient and agent object has been studied (Leslie & Keeble, 1987). Leslie and Keeble (1987) claim that infants around 6 months of age are successful in registering the reversal of the collision events. The reversal of the collision events is when the patient object propels an agent object to move in the opposite direction (Leslie &

Keeble, 1987). Despite this, yet no studies to date have examined the size of the patient object after infants' successful perception of the size of the agent object (Kotovsky & Baillargeon, 1998; Hohenberger et al., 2012).

Despite the lack of findings, the eighth experiment was an easier version of the seventh experiment in this chapter. This can be explained by the encoding differences of the events in these experiments. In the eighth experiment, the cube is present during the entire collision event and can be contrasted with the other cubes below the ramp. Furthermore, the agent object that is off view at certain times has a constant size throughout all events. However, in the seventh experiment, the agent object is not present at the start of the test event, but is later presented by a hand that puts it on the ramp, before it rolls down. This might not give infants enough time to encode and distinguish between the sizes of the agent object and the two other objects below the ramp. For that reason, the size relationship in the eighth experiment can be understood easily compared to the seventh experiment. Furthermore, it is a more complex matter to relate size of one agent object to distance propelled of another object (Experiment 7) as opposed to relate size of one patient object to distance propelled of this same object (Experiment 8).

Limitations

Chapter 5 results suggest that the task of perceiving mass cues of agent and patient object size in the collision events might have been ambiguous or complex for an infant audience. Infants need to consider a number of variables for Experiment 7 such as a) size of the balls and cube, b) size of the balls and the cube in relation to one another, and c) the likely displacement followed by this collision. For that reason, putting these variables together might create ambiguity and require complex skills beyond infants in this age range.

Conclusion

The experiments in this chapter fail to provide evidence that infants consider mass cues of object size of agent and patient object in collision events.

Chapter 6 – Discussion

6.1 General Discussion

The brightness-weight and pitch-weight cross-sensory weight associations and their mass cues in collision events are predicated on the claim that weight and mass are in synchrony with one another (Woodworth, 1921; Payne, 1958; Ross, 1969; Ross & Di Lollo, 1970; Stevens & Rubin, 1970). Objects of heavier weights are always heavier in mass (Ross, 1969; Ross & Di Lollo, 1970; Stevens & Rubin, 1970). Furthermore, literature suggests infants and adults consider object properties such as size and their cues to mass in collision events (Kotovsky & Baillargeon, 1994;1998; Hohenberger et al.,2012; Vicovaro & Burigana, 2014; 2016). The present thesis finds its basis in theories explaining adults', childrens', and infants' consideration of object properties alone, in relation to momentum outcomes in collision events. This chapter will review findings of the eight experiments and discuss how they contribute to the current understanding of object properties and masses in collision events, and outline future directions to investigate this gap in the literature.

6.1 Summary findings

This thesis presents eight empirical experiments that considers the developmental trajectory of the perception and reasoning of object properties and their cues to mass in collision events. Adults were investigated beforehand to validate the alternative methodology to Kotovsky and Baillargeon (1994,1998). Adults were examined on the size-mass, brightness-mass, and pitch-mass associations in collision events. Furthermore, the experimental findings with adults served as building blocks for the subsequent investigations with infants. Thus, the sequence of the investigations of each age group are built on previous experiments of this thesis. Infants of 6-to-7–months and 10-to-11- months were investigated.

This thesis comprised of the following sequence of experiments:

Chapter 3 investigated adults' reasoning about object size, object brightness, and sound pitch during collision and their cues to mass in collision events.

Chapter 4 examined 6-7-month old infants' perception of object size, object brightness, and object size+brightness and their cues to mass in collision events.

Chapter 5 explored 10-11-month old infants' use of object size of agent and patient object as a cue for mass in collision events.

The results of Chapter 3 suggest that adults sometimes consider mass cues of visual object properties such as size and object brightness in collision events. However, adults fail to consider the mass cues of pitch sound in the collision events. The results in Chapter 4 indicate that the findings of the experiments fail to provide evidence that infants perceive mass cues of object properties size, brightness, and size and brightness in collision events. The experiments in Chapter 5 present findings that fail to provide evidence that infants consider mass cues of object size of agent and patient object in collision events.

6.2 Explanation of findings

Results from Chapter 3 support the hypothesis for Experiment 1 and 2. Experiment 3 did not produce results in line with our hypothesis. However, adults gave higher ratings to the shorter distance the cube was propelled to for both high and low pitch sounds. Adults sometimes considered the mass cues of size and brightness in line with our hypothesis in the collision events. Adults judged the congruent test event outcomes higher in comparison to incongruent test event outcomes. Furthermore, the outcomes in which the small size and bright ball propelled the cube to a shorter distance were judged more likely compared to the events in which the small size and bright ball propelled the cube to a longer distance.

An important caveat is that these findings were only observed for small ball and bright ball. Adults expected the small ball to propel a patient object to a shorter distance. This can be explained by the size and force relationship. Small objects are usually less in mass, thus exert less force and lack the ability to push a larger (mid-size cube) patient object far. Similarly, adults expected the bright ball to propel a patient object to a shorter distance. This can be explained by the colour and mass inference. For example, some participants commented on the resemblance of the bright ball with a ping-pong ball and further made mass suggestions in that direction. Bright objects are usually perceived to be lighter in weight (Walker, 2012). Moreover, adults in our pitch experiment displayed a preference for shorter distance for all test events regardless of pitch sound. Adults rated the shorter distance for both high and low pitch sounds higher compared to longer distance. This could mean that visual information about the object thus its same size and colour would be attended to in preference to auditory information across events (low or high pitch collision sound). Attendance to visual information that is consistent through events would result in the assumption that test events are identical. This suggests that adults might have aid their visual attention when judging collision events and this might have overridden their auditory attention to pick up the sound pitch. Alternatively, one reason pitch did not work could be that the pitch of the contact sounds is a product of both objects and not just the launch object so it is not a reliable cue to launch object mass.

Chapter 3 presents findings that extend the cross-sensory literature on object brightness, sound pitch and their relationship to mass. These experiments present novel findings for object brightness and pitch sound in the context of collision events. Previous studies have examined object properties brightness and sound pitch, but not in collision events (Walker, 2012). These object properties have been associated with weight (Walker, 2012). Object size in collision events has been assessed with adults previously (Schiff & Detwiler, 1979). Adults' judgement of approaching collisions was assessed by different object sizes in the collision events (Schiff & Detwiler, 1979). Chapter 3 extends the previous studies examining object size by using comparisons of real-life based likeliness and reference related likeliness assumptions adults hold about object size in the context of collision events. Collision events involve a number of variables that needs to be considered before making a judgement of the collision events. For that reason, judging weights of object properties brightness and sound pitch (Walker, 2012) is different than considering the mass cues of these objects in collision events. In the case of pitch sound, the judgement of collision events requires both visual and auditory attention. Attention to visual information might override the auditory information that cues mass in collision events.

Results from Chapter 4 suggest that infants fail to perceive the mass cues of object size, object brightness, and size+brightness in the collision events contrary to our hypothesis. Post-collision analyses for all experiments in this chapter suggest that infants have a distance preference for longer distances. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. This could be explained by the longer duration of these animations. The animations were longer for the events in which the cube was propelled to the endpoint of the screen compared to the events in which the cube was propelled before the midpoint of the screen. I like to argue that infants' total looking times do not indicate whether infants have seen the post-collision that determines the outcome of the collision event. Infants can choose to look away for 2 seconds during post-collision and retain their attention to the collision event thereafter. This means that they might have missed the integral part of the collision event. For that reason, we have chosen to analyse post-collision looking time in addition to our total looking time analyses. In the total looking time analysis infants demonstrated a size preference for the large ball demonstrated by their longer looking time to large ball test events compared to small ball test events (Newman et al., 2001). Moreover, when all experiments of

Chapter 4 were compared, infants demonstrated longer total looking times to objects that cued more mass compared to objects that cued less mass. The analysis of the pooled results for Experiments 4, 5 and 6 can be interpreted as showing that infants were indeed sensitive to the differences in cues that indicate mass such as size and brightness, but just didn't use them when presented with collision events. However, this finding was only revealed when all the experiments were contrasted. For that reason, it can also be assumed that increased statistical power might have resulted in these findings.

Total and post-collision looking time analyses suggest that infants do not perceive object size and its cues to mass in the collision events. The previous findings by Kotovsky and Baillargeon (1998) and Hohenberger et al., (2012) could not be replicated. Furthermore, results from the total and post-collision looking time analyses suggest that infants did not perceive object brightness, and size+brightness and their cues to mass in the collision events. Objects in the experiment assessing brightness and mass relationships were of same size but differed in brightness. No difference in looking time across test events might indicate that infants held similar perception of all objects because the objects were of the same size. Alternatively, the relationship between object brightness and mass that is prominent in adults might not exist in this age range (6-7 month olds). Conversely, the experiment assessing the two mass cues of object size+brightness (experiment 6) produced similar results in line with Experiment 4 and 5. This again, suggests that infants might lack the ability to perceive the mass cues of object size+brightness in the collision events. In sum, these experiments suggest that infants between 6 and 7 months of age might lack the ability to perceive the mass cues of the object properties size, brightness, and size+brightness in collision events.

Experiments on object brightness, and the combination of object size and brightness present a novel approach to examining the relationship between these object properties and mass in 6 to 7 month old infants. Previously, object size is the only object property that has been examined in collision events with 6 to 7 month olds (Kotovsky & Baillargeon, 1998). Previous findings demonstrated that infants perceive the relationship between size and mass in collision events based on total looking time at events (Kotovsky & Baillargeon, 1998). We failed to replicate these findings with our total looking time analyses of test events. Similarly, Hohenberger et al. (2012) have not been successful with replicating these findings with their 6-to-7-months-old sample using animated collision events. However, Hohenberger et al. (2012) were successful with their 10-to-11- months-old sample despite using animated objects (Hohenberger et al., 2012).

One of the reasons we failed to replicate with 6-to-7-month old infants could be that the collision events in Kotovsky and Baillargeon's (1998) study were 3D real-life rather than 3D computer-generated objects. Furthermore, the collision events by Kotovsky and Baillargeon (1998) were colourful and included two cues to distinguish between the variables on only one distance. The colourful display could be more captivating for infants and could also explain our high dropout rate for all infant experiments. Similarly, Kotovsky and Baillargeon (1998) compared the looking between the large and small cylinder on the same trajectory rather than two separate trajectories which might explain our results. However, our experiments controlled for colour and used one cue at the time on two different distances (long and short trajectory). We wanted to disentangle the colour and size cues to only one cue (size). Similarly, we wanted to compare infants' perception of the violation for both object sizes rather than one like in the original experiment by Kotovsky and Baillargeon (1994;1998). Matching long and short trajectory results for each object property might remove the distance effects we seem to get for all experiments when data is analysed post-collision. Our experiments unlike Hohenberger et al (2012) had an impact sound during collision for each event and this sound was recorded by hitting a billiard ball with a wooden cube. Furthermore, our 3D computer generated collision events had a hand that set the objects in movement that Hohenberger et al., (2012) did not consider. Objects in our animations were set in motion by a hand that acted like an outside agent.

Walker (2012) demonstrated adults associated darker objects with heavier weight and brighter objects with lighter weight. Pre-schooled children make similar judgements (Plack & Shick, 1976), and we are aware that judging object properties based on weight and judging outcomes of collision events based on object properties require different skills and differ in complexity. Furthermore, this association between brightness and weight might not exist in infants between 6 and 7 months of age. Infants make associations between brightness and pitch around 10 months of age (Haryu & Kajikawa, 2012). Brighter colours are associated with higher pitch sounds and darker objects with lower pitch sounds by 10 month olds (Haryu & Kajikawa, 2012). These findings suggest that 10 month olds pair higher mass objects together and lower mass object properties together. Infants in the study by Haryu and Kajikawa (2012) were 10 months of age, older than our sample. Even if infants held some knowledge about the object properties examined in Chapter 4, it might not necessary suffice for understanding it in the context of collision events. In the context of collision events, infants need to perceive several variables such as a) the properties of the balls and the cube, b) the properties of the ball and the cube in relation to one another, and c) the likely force one object with certain properties will exert on another object with certain properties.

Results from Chapter 5 suggest that infants fail to consider the mass cues of size of agent and patient object in the collision events contrary to our hypothesis. Post-collision analyses for Experiment 7 in this chapter suggest that infants have a distance preference for longer distances. Infants looked longer at the events in which the cube was propelled to longer distance compared to shorter distance. This could be explained by the longer duration of these animations. The animations were longer for the events in which the cube was propelled to the endpoint of the screen compared to the events in which the cube was propelled before the midpoint of the screen. Post-collision analyses for Experiment 8 in this chapter suggest that infants have a distance preference for shorter distances. Infants looked longer at the events in which the cube was propelled to shorter distance compared to longer distance. Male infants display looking time differences between congruent and incongruent test events for small cube in line with our hypothesis. Male infants looked longer at small cube incongruent test event compared to small cube congruent test event. Furthermore, male infants display total looking time differences between congruent and incongruent test events for large cube in line with our hypothesis. Male infants looked longer at large cube incongruent test event compared to large cube congruent test event. An important caveat to this is that previous findings by Hohenberger et al., (2012) that assessed total looking time of collision events could not be replicated. No total looking time differences between congruent and incongruent events in Experiment 7 can be explained with the same explanations given in Experiment 4. Experiment 7 was identical to Experiment 4 in Chapter 4, but the age tested was different. In Experiment 4 infants between 6-to-7-months and in Experiment 7 infants between 10-to-11-months were tested. These age groups were targeted due to Kotovsky and Baillargeon's (1998) successful results with these age groups. Furthermore, Hohenberger and colleagues (2012) managed to replicate their animated version of the original collision event experiment by Kotovsky and Baillargeon (1998) with 10-to-11-month-old infants.

Experiment 8 presented a novel approach to examine the relationship between mass and the size of patient object in collision events. However, the results were not in line with our hypothesis. Infants failed to differentiate between congruent and incongruent test events. No total looking time differences between congruent and incongruent events could mean that infants did not consider the size-mass relationship of the patient object. The relationship between size of the patient object and its cues to mass in collision events has not been studied before. Experiment 8 was therefore an attempt to extend the previous knowledge of object size in collision events. Previous studies have examined the relationship between the size of the agent object and mass in real-life 3D and animated collision events with 6-to-7 and 10-to-11-month olds (Kotovsky & Baillargeon, 1994;1998; Hohenberger et al., 2012). These previous investigations noted infants attend to the size-mass relationship, yet our findings contradict those previously reported. Moreover, in Experiment 8, the task was simplified by making both mass cues and distance propelled relate to one object, the cube. Thus, the task was simplified by removing the need to relate one object's mass to another object's movement. Collision events in Experiment 8 were easier to understand than the collision events in Experiment 7. Furthermore, in Experiment 8 infants were assessed on the size of the cube that were in view and could be contrasted with the other two cubes below the ramp during the entire collision event. Infants in Experiment 7 viewed collision events in which the agent object was not present at the start, but was later in view. This difference could mean that infants in Experiment 8 had more time to encode and contrast stimuli size than infants in Experiment 7.

6.3 Future directions and theoretical implications

Collision events still remains as one of the early forms of infant testing on causality and physical knowledge to understand how infants perceive object interactions (Baillargeon, 2002). The preference for certain types of collision events is claimed to be present very shortly after birth and demonstrated with the use of animated collision events (Mascalzoni, Regolin, Vallortigare, & Simion, 2013). This preference is claimed to later develop into a perception of collision events around 2.5 months of age (Baillargeon, 1995; Kotovsky & Baillargeon, 1994). Infants perceive a patient object to move after a collision with an agent object, but not after a delay between the two objects (Baillargeon, 1995; Kotovsky & Baillargeon, 1994). Furthermore, it is claimed that around 6-to-7-months of age, infants start to perceive object size of agent object in collision events (Kotovsky and Baillargeon (1994;1998). Yet, a recent animation experiment only worked with 10-to-11-month olds but not 6-to-7-month olds (Hohenberger et al., 2012).

In the original experiment by Kotovsky and Baillargeon (1994) a hand was manipulating the real-life objects. The failure to replicate the original findings with 6-to-7-month olds might stem from the methodological differences across these experiments. For example, in the original experiment by Kotovsky and Baillargeon (1998), 3D real-life objects that a hand manipulated were used, whereas in Hohenberger et al. (2012) experiment 2D objects were used. The results might then differ across these experiments due to various reasons such as infants' failure to perceive the 2D objects as violating expectations compared to 3D real-life objects or the lack of time permitted to encode the events on the display (Munkata, 2000). Infants between 6 and 7 months of age might still attend and be familiar with object size despite their failure to perceive the impossible events in the experiment of Hohenberger et al (2012). This might explain why the looking time for the impossible events do sometimes demonstrate a familiarity to the event (Munkata, 2000).

The original findings by Kotovsky and Baillargeon (1994;1998) might also have been misinterpreted. For example, 6-to-7-month old infants in their study look longer at the event in which the small ball propels a patient object to the endpoint of the screen compared to the same event with the large ball. This result would be interpreted as infants perceive the violation of the event based on object size changes. However, the wrong theory might have been applied to understand this looking time data. Alternatively, longer looking time to small ball test events might indicate infants' unfamiliarity to the event rather than the perception of size change.

The original experiment by Kotovsky and Baillargeon (1998) presented some limitations as mentioned in Chapter 1 that we controlled for in our experiments. We controlled for colour and included one more distance (shorter distance) to compare between the large and small size agent object. Similarly, we controlled for colour of surrounding and visual display. However, these methodological differences in our experiments might have produced the lack of findings of our experiments. For example, the object size differences were not as prominent in our experiments in comparison to the experiment of Kotovsky and Baillargeon (1994;1998). The size differences of the objects followed dimensions that complied with the size-appropriate distances the patient object could be propelled to considering the force and distance relationship. Similarly, the collision events were 3D computer generated, the collision events could have been created with 3D real-life objects or videos of 3D real-life object collision events. The 3D computer-generated collision events could have been closer to Walt Disney animations. An eye-tracker could have been employed instead of video recordings and the use of Habit for looking time data. Infants eye-tracking of the trajectory after collision would suffice infants' expectations of events. However, the original experiment by Kotovsky and Baillargeon (1994) was conducted using Habit software. For the purpose of replicating the size and mass experiment, we followed the similar technique of Kotovsky and Baillargeon (1998). Moreover, our experiments could be conducted with a larger sample. We analysed our data using total looking time and post-collision looking time, proportional looking times (or rather, looking durations scaled by the duration of the trials might have been more appropriate when considering the comparison across different trajectories.

Future research could benefit from a study examining the methodological differences and findings of object size in collision events. Hohenberger et al (2012) successful replication with 10-to-11 month olds are not in line with our findings with the 10-to-11-month old infants.

Furthermore, future research could benefit from a large sample size study examining object size in collision events by employing an eye-tracker. The eye-tracker could provide information about whether infants anticipate a certain distance the cube will be propelled to, based on the size of the agent object. Similarly, both adults and infants could have been matched on competence by being tested with an eye-tracker. In our experiments adults reasoned whereas infants perceived the object properties and mass cues in the collision events. For that reason, the results cannot be interpreted similarly.

These mentioned suggestions for future research could also be applied to all experiments in this thesis. The suggested future research can be beneficial in establishing a theoretical framework concerning infants' perception of object size and other object properties in collision events. Three experiments have been conducted on this topic so far (Kotovsky & Baillargeon, 1994;1998; Hohenberger et al., 2012), and these experiments are not enough to conclude that infants perceive object size in collision events in the infant literature. This theoretical framework needs therefore to be strengthened with experiments that support these findings and fail to support these findings. Furthermore, there is a gap in the infant literature concerning infants' perception of other object properties in collision events. Future research could also benefit from meta-analyses assessing the methodological differences across experiments and the outcome of whether infants perceive object size and other object properties in collision events.

A question that has persisted throughout this thesis that I have not provided an answer for in this thesis but would like to give an interpretation to with future experiments is; Do infants perceive object properties and their cues to mass in collision events? Our total looking time and post-collision looking time suggest otherwise, however eye-tracking data might yield different outcomes. For that reason, I cannot be certain and can only interpret the data based on my own findings using the looking time paradigm.

6.4 Concluding remarks

To summarise the reported findings, Chapter 3 results suggest that adults sometimes consider mass cues of visual object properties such as size and object brightness, but fail to consider mass cues of pitch sound in collision events. Results of Chapter 4 indicate that infants fail to perceive mass cues of object size, brightness, size+brightness in the collision events. The results of Chapter 5 fail to provide evidence that infants consider mass cues of object size of agent and patient object in collision events.

Our experimental chapters that assessed object size, object brightness and pitch sound in adults, object size of agent and patient object in 10-to-11-month old infants, and object size, object brightness, and object size+brightness in 6-to-7-month old infants suggest that further research is needed in these topics. Furthermore, the findings of the infant experiments that assessed object size in collision events indicate that future research is essential to either accept or reject this theory that infants perceive the relationship between size and mass.

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