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[Towards a Complete Commonsense Theory of Motion: The Interaction of Dimensions
in Children's Predictions of Natural Object Motion](#)

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Differentiation of Dynamic Events:
The Interaction of Dimensions in
Children's Predictions of Natural
Object Motion

Abstract

Events involving motion in fall are differentiated psychologically from events involving horizontal motion. Do children associate motion down inclines more with motion along horizontals or more with motion in fall, or do they even treat it as an integration of the two? The question was raised over 20 years ago but never satisfactorily answered, so the principal aim of the reported research was to take matters forward. Children ($n = 144$) aged 5 to 11 years were assessed while predicting natural dynamic events along a horizontal, in fall, and down an incline. They were required to make predictions of speed with heavy and light balls and under changes in incline heights. The results show that, consistent with previous work, faster horizontal motion was associated with the light ball across all ages whereas faster fall was associated with the heavy ball. However, while the younger children predicted faster incline motion for the lighter ball, there was a shift in this conception towards older children predicting faster motion for the heavier ball. Understanding of how changes in incline height affect speed was generally good, with this aspect of the study helping to establish how children perceive diagonal dimensions. How supported horizontal motion and unsupported fall motion may affect children's changing understanding of incline motion is discussed, thus providing more complete insight into children's understanding of natural object motion than has been established so far.

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Introduction

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4 It is now widely accepted, on the basis of numerous studies (cf. Duit, 2009), that
5 children do not come to formal science teaching as tabula rasa, but that they possess rich
6 prior conceptions about the physical world. They have beliefs and expectations about how
7 things happen which enable them to predict future events. Children construct this knowledge
8 on the basis of everyday experiences and interactions (King, 1960; Klaassen, 2005;
9 Vosniadou & Ioannides, 1998), and seem strongly committed to their beliefs and
10 expectations. One particularly ubiquitous element of the physical world is object motion,
11 perhaps because it is experienced from the first day of life. Children's conceptions about
12 object motion have, therefore, been extensively studied, but uncertainties continue to exist.
13 One such uncertainty informed the study to follow.

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16 "Vertical gravity is a constant fact of life, so vertical dimensions should be treated
17 differently from horizontal dimensions" (Hayes, 1979, p. 256). This claim suggests that
18 events involving downward motion are differentiated psychologically from events involving
19 horizontal motion (Howe, 1998). Through several theoretical and empirical papers Ogborn
20 and colleagues (Bliss & Ogborn, 1988; Bliss, Ogborn, & Whitelock, 1989; Ogborn, 1985)
21 attempted to construct a commonsense theory of motion on the basis of this psychological
22 differentiation. Their theory outlines a relationship between two particular features of motion
23 – support and falling. If an object has support it does not fall and if it does not have support it
24 falls, until it is supported. They further note that "motions which go up or down are
25 distinguished from those which merely 'go along'" (Bliss & Ogborn, 1988, p. 121).

26
27 Although Ogborn and colleagues' commonsense theory may be partially true, it does
28 not seem entirely satisfactory: Motion down inclines is as much motion going up or down as
29 it is motion that merely goes along. Despite one task (out of 15) requiring children aged 6 to
30 10 years (Bliss & Ogborn, 1988) and 11 to 18 years (Bliss et al., 1989) to consider motion
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2 down an incline, their work has principally focused on support versus no support in scenarios
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4 of fall or horizontal trajectories in air. The one task considering incline motion merely
5
6 required an understanding of whether or not something would slide down an incline if
7
8 pushed. Bliss et al. (1989) note the unsatisfactory nature of their analysis of motion down an
9
10 incline, and the uncertainties remain to this day. An answer is still required to the question:
11
12 Do children associate motion down inclines more with motion along horizontals (because of
13
14 support), or with motion in fall (because of gravity), or are they able to integrate the two to
15
16 some extent?
17

18 The importance of filling this gap in the commonsense theory lies in the fact that
19
20 despite rich prior conceptions about the world, the ideas children bring into the classroom are
21
22 often found to be highly resistant to change and instruction (Bloom & Weisberg, 2007; Chi,
23
24 2005; Duit, Treagust, & Widodo, 2008), particularly in the field of dynamics (diSessa, 1996;
25
26 Tao & Gunstone, 1999). These ideas often persist into adulthood and affect subsequent
27
28 learning (Reif, 2008; Sherin, 2006). Current approaches to conceptual change in this field are
29
30 thus not satisfactory in eliciting or facilitating change sufficiently. A more complete
31
32 commonsense theory of children's understanding of object motion across age groups could
33
34 have a positive impact on teaching strategies. In particular, they could be more suitably
35
36 adapted to the needs of a given age group, in accordance with the developmental trend of
37
38 such understanding, which may in turn show to be more effective in working toward
39
40 successful conceptual changes.

41 There do not appear to be any studies that have examined the same children's
42
43 reasoning about motion along a horizontal, object motion in fall *and* object motion down an
44
45 incline. Testing the same children on all three dimensions would provide the clearest
46
47 information of relevance to specifying a commonsense theory. Noting in addition that age-
48
49 related changes would help to clarify the status of incline within an overall commonsense
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1
2 theory and its fruitfulness for teaching strategy development, the study that follows also
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4 examines conceptions across a broad age range, i.e. 5 to 11 years. A clue to children's
5
6 understanding may come from research into how object mass affects predictions of motion in
7
8 the three dimensions, i.e. horizontal motion, motion in fall, and motion down an incline.
9
10 While in reality mass is a negligible influence upon falling or rolling objects (instead, speed
11
12 is affected by such factors as surface area or material density), mass-related outcomes are
13
14 probably among the most predominant pre-conceptions that children hold, corresponding
15
16 perhaps to a typically Aristotelian view of the world (Galili, 2001).

17
18 As regards motion in fall, previous research is relatively consistent, with faster
19
20 descent largely being associated with heavy objects across a range of ages (Baker, Murray, &
21
22 Hood, 2009; Chinn & Malhotra, 2004; Hast, 2011; Nachtigall, 1982; Sequeira & Leite, 1992;
23
24 van Hise, 1988). With horizontal dimensions, however, there is less consistency. Faster
25
26 motion sometimes seems to be associated with lighter objects in older participants (Maloney,
27
28 1988) and sometimes with heaviness (Howe, 1991, as cited in Howe, 1998; Inhelder &
29
30 Piaget, 1958). The latter work however suggests that children up to 12 years view heaviness
31
32 as a hindrance to horizontal motion. The limited research into incline motion also shows
33
34 signs of inconsistency, but here there are hints of changes with age (Howe et al., 1992, as
35
36 cited in Howe, 1998; Inhelder & Piaget, 1958).

37
38 One further factor that may help to clarify children's conceptions of motion in the
39
40 three dimensions is their responses to changes in incline height. Do young children appreciate
41
42 that when inclines are raised objects roll down faster and when inclines are lowered objects
43
44 roll down slower? The importance of this lies in the fact that changes in incline height cause
45
46 changes in motion, even when the objects do not change their mass. In addition, raised
47
48 inclines are closer to the vertical dimension and lowered inclines are closer to the horizontal.
49
50 Accordingly, the study to follow included two different incline heights.

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2 In short, the research to follow attempted to establish a clearer picture of children's
3 understanding of natural object motion in the interests of developing the commonsense theory
4 of motion put forward by Ogborn and colleagues (Bliss & Ogborn, 1988; Bliss et al., 1989;
5 Ogborn, 1985). Particular consideration was given to the psychological differentiation of
6 horizontal, incline and falling motion by addressing the understanding that children of a
7 broad age range show as a function of both object mass and incline height.
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13 14 15 16 **Method** 17 18 19

20 **Overview** 21 22 23

24 To clarify children's commonsense theory of motion a number of features were
25 incorporated in the present study's design. The general lack of accountability of incline
26 dimensions was addressed by having children predict motion along a horizontal, in fall and
27 down an incline. To provide a stronger account the same children responded to all tasks. As
28 mass was indicated as being a helpful factor in establishing children's motion understanding
29 a heavy and a light ball were incorporated. The same balls were used for predictions across
30 all three motion types. Balls are useful objects, as they have extremely low friction
31 coefficients. This means that object friction does not play a crucial role, and comparisons
32 between the three motion types can be established more easily. Finally, two different incline
33 heights were incorporated into the present work. The study described here thus involved a
34 mixed design with four age groups (between-participants) spanning the primary school age
35 range and all participants responded to all three dimensions as well as the mass and incline
36 height variations (within-participants).
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Participants

Participants were recruited from a state primary school located in a suburban area of Cambridge, United Kingdom. The sample was drawn from those children whose parents did not object to their participation, and who, when they were non-native speakers of English, were identified by class teachers as capable of understanding the research instructions. This amounted to 144 children (80 girls), including 36 Year 1 children (20 girls; age $M = 5.70$ years, $SD = 0.32$), 36 Year 2 children (21 girls; age $M = 6.68$ years, $SD = 0.26$), 36 Year 4 children (21 girls; age $M = 8.64$, $SD = 0.33$) and 36 Year 6 children (18 girls; age $M = 10.77$, $SD = 0.25$).

Design and materials

The materials consisted of a transparent acrylic tube of 101.5cm length and with an internal diameter of 6.5cm. A wooden frame allowed the tube to be placed at inclines of two different angles such that the starting point of motion inside the tube could be at either 15cm or 30cm height. A paper track of 101cm length and 10cm width was placed underneath the opening of the tube when placed at an incline (see Figure 1). Two test balls were used; one was a bright pink standard table tennis ball and one was a dark green solid glass marble. Both balls were approximately 4cm in diameter, but the table tennis ball weighed approximately 3g while the marble weighed approximately 75g. In addition, one practice ball was used, a standard squash ball (approximately 4cm in diameter).

[Insert figure 1 about here]

1
2 Eight different questionnaires (one to be used per child) were used to guide the tasks
3
4 and for the researcher to note children's responses to questions. There were four separate
5
6 sections within each questionnaire – two concerned with motion down an incline (of which
7
8 one concerned motion after a change in incline height), one concerned with motion along a
9
10 horizontal, and one concerned with motion in fall (see Table 1). The section covering
11
12 horizontal motion always came after those concerned with motion down inclines because
13
14 horizontal motion could then be depicted as rolling along the track after incline descent. As a
15
16 result, horizontal motion, like motion in the other dimensions, could be achieved without
17
18 pushing or pulling. The two sections covering questions about motion down inclines were
19
20 also paired together to facilitate instructions. For the section concerning motion after a
21
22 change in incline, one ball only was used, either the glass marble ('heavy') or the table tennis
23
24 ball ('light'). There were altogether three control questions and eight test questions as
25
26 detailed below. Each child was expected to answer all questions. Equal numbers of children
27
28 per age group were selected at random for each questionnaire.
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32 [Insert table 1 about here]
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36 Procedure

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40 The interviews took place in an open and publicly accessible area of the children's
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42 school. Upon arrival, each child was given general information about the study – that the
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44 researcher had brought a fun science experiment and there were going to be some questions
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46 about it. To begin with, the child was introduced to the apparatus and the three balls. The
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48 balls could be handled at any time, but the child was prevented from carrying out any
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2 relevant actions when responding to the questionnaire items, i.e. rolling the balls across the
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4 table or deliberately letting them fall were not permitted.

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6 At the beginning of each questionnaire section (with the exception of the section
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8 concerning motion after incline changes) the child was given a control question, which only
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10 required some general statement about what would happen to the practice ball if it were held
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12 into the tube and then released, i.e. that the ball would roll or fall down the tube. The same
13
14 question was asked for the horizontal motion block but emphasis was placed on the ball's
15
16 behaviour along the track rather than the tube. This question was asked to ensure the child
17
18 understood the apparatus and was familiar with the general concepts involved.

19
20 For the two test questions relating to fall motion, the child was given the following
21
22 first instruction (italics were stressed by the researcher in speech): "Imagine you have *two*
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24 tubes like this one next to each other, and they are *exactly the same*. Then imagine you are
25
26 holding both balls with your hands in the tube, like this [researcher demonstrated this action
27
28 with hands] and you let them both go at the *same time*." The child was then asked two
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30 questions. The first question was: "Do you think one of the two will fall down to the bottom
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32 of the tube faster, or do you think they will both fall as fast as each other?" The second
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34 question was: "Do you think one of the two will take longer to fall down to the bottom of the
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36 tube, or do you think they will both take as long as each other?"

37
38 For the two test questions relating to motion down the first incline, regardless of
39
40 incline height, the child was given the following instruction: "Imagine you have *two* tubes
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42 like this one next to each other, and they are *exactly the same*. Then imagine you are holding
43
44 both balls with your hands in the tube, like this [researcher demonstrated this action with
45
46 hands] and you let them both go at the *same time*." The child was then asked two questions.
47
48 The first question was: "Do you think one of the two will roll down to the end of the tube
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50 faster, or do you think they will both roll as fast as each other?" The second question was:
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2 “Do you think one of the two will take longer to roll down to the end of the tube, or do you
3 think they will both take as long as each other?”
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6 For the two test questions relating to the second incline, the child was given the
7 following first instruction: “Now watch this. If I put the tube here [researcher changes tube
8 from high to low incline or vice versa], and you let *this* ball [researcher points out
9 comparison ball] roll down the tube.” The first question was: “Do you think it will roll faster
10 than before, or slower than before, or do you think it will roll as fast as it did before?” The
11 second question was: “Do you think it will take more time than before, or less time than
12 before, or do you think it will take as much time as it did before?”
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20 Horizontal motion was always considered using the first of the two incline heights,
21 and the apparatus was changed back to how it was initially set up for the first incline. For the
22 two test questions the child was given the following first instruction: “Remember how we just
23 pretended the two balls were rolling down at the same time? Imagine you have *two* tubes like
24 this one next to each other again, and they are *exactly the same*. Now imagine you are
25 holding the two balls into the tube, like this [researcher demonstrated this action with hands]
26 and you let them go and they reach the bottom of the tube [researcher points out the tube exit]
27 at the *same time* and the balls roll out along here, all the way to the end [researcher points
28 along the paper track].” The child was then asked two questions. The first question was: “Do
29 you think one of the two will roll to the end faster, or do you think they will both roll as fast
30 as each other?” The second question was: “Do you think one of the two will take more time
31 to reach the end, or do you think they will both take as long as each other?”
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43 For each question, there was a choice between three responses: The child could select
44 one of the two objects over another, or state that both would behave the same. In addition, the
45 child was asked to provide justifications, i.e. state why they had made their choices. At the
46 end of each questionnaire section the child was given the option either to take a short break or
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2 to continue with the questions for the next motion dimension. The apparatus was then
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4 modified as necessary.
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8 9 **Results**

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11 All children passed all three control questions (predictions for the practice ball), so
12 data from all children qualified for analysis. Two justification types were identified from the
13 responses. These were references to the objects' mass or texture. All justifications referred to
14 mass, i.e. texture was always in conjunction with mass. Since texture references were also
15 very rare, the analysis focused upon mass alone. For purposes of analysis, mass was broken
16 down into 'heavy' and 'light'. No misattribution of mass was observed; no child stated the
17 table tennis ball was heavier than the glass marble or vice versa.
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26 Kolmogorov-Smirnov tests on normality of distribution showed that distributions for
27 all datasets deviated significantly from normality, implying that assumptions for parametric
28 tests were not met. Mean scores were analysed using Friedman's ANOVAs and post hoc
29 Wilcoxon signed-rank tests, with Bonferroni corrections applied (all significance thresholds p
30 ≤ 0.025). Effects of gender and ball type were analysed with Mann-Whitney tests. Effects of
31 age and of question order were analysed with Kruskal-Wallis tests and post hoc Jonckheere-
32 Terpstra tests. No significant gender or question order effects were found, therefore these
33 factors are not considered further. All data were analysed using PASW (Predictive Analytics
34 Software, formerly SPSS) Statistics version 18.
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44 There was significant variation among mean scores for overall faster motion response
45 options, whether the heavy ball or the light ball would be faster, or whether the two would be
46 the same, $\chi^2(2, n = 144) = 208.80, p < 0.001$. Different-speed options ($M = 5.81, SD = 0.47$)
47 were chosen significantly more often than same-speed options ($M = 0.19, SD = 0.47$), $T = 11$,
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2 $r = -0.94$. However, there was no overall significant difference between choosing the heavy
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4 or the light ball as being faster. There was a significant interaction of age with mean scores
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6 for choosing the heavy ball as faster, $H(3) = 28.22, p < 0.001$. Mean scores increased with
7
8 age, $J = 5188, z = 4.84, r = 0.40$. There was also a significant interaction of age with mean
9
10 scores for choosing the light ball as faster, $H(3) = 31.46, p < 0.001$. Mean scores decreased
11
12 with age, $J = 2433, z = -5.38, r = -0.45$. There was no significant interaction of age with mean
13
14 scores for same-speed options.

15
16 Figure 2 shows the mean scores by age group for motion along the horizontal, i.e. the
17
18 mean number of responses indicating that the heavy ball would be faster, the light ball would
19
20 be faster, and the two balls would be the same. A maximum score of 2 was obtainable. There
21
22 was significant variation among mean scores, $\chi^2(2, n = 144) = 191.85, p < 0.001$. The light
23
24 ball ($M = 1.66, SD = 0.57$) was predicted significantly more often to be faster than the heavy
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26 ball ($M = 0.28, SD = 0.52$), $T = 9, r = -0.78$. The heavy ball being faster was predicted more
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28 frequently than making a same-speed prediction ($M = 0.06, SD = 0.23$), $T = 11, r = -0.88$.
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30 Age did not interact significantly with mean scores: regardless of age, the children
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32 consistently predicted the light ball to be faster.

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36 [Insert figure 2 about here]
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41 Figure 3 shows the mean scores by age group for motion in fall, i.e. whether the
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43 heavy ball or the light ball would be faster, or whether the two would be the same. A
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45 maximum score of 2 was obtainable. There was significant variation among mean scores,
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47 $\chi^2(2, n = 144) = 197.26, p < 0.001$. The heavy ball ($M = 1.66, SD = 0.56$) was predicted
48
49 significantly more often to fall faster than the light ball ($M = 0.27, SD = 0.49$), $T = 10, r = -$
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51 0.80. The light ball falling faster was predicted more frequently than making a same-speed
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2 prediction ($M = 0.06$, $SD = 0.23$), $T = 4$, $r = -0.30$. Age did not interact significantly with
3
4 mean scores: regardless of age, the children consistently predicted the heavy ball to be faster.
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8 [Insert figure 3 about here]
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12 Figure 4 shows the mean scores by age group for motion down the first incline
13 regardless of incline height, i.e. whether the heavy ball or the light ball would be faster, or
14 whether the two would be the same. A maximum score of 2 was obtainable. There was
15 significant variation among mean scores, $\chi^2(2, n = 144) = 93.76$, $p < 0.001$. There was no
16 significant preference for predicting either of the balls as being faster. However, predicting
17 the heavy ball to be faster ($M = 1.00$, $SD = 0.84$), $T = 8$, $r = -0.68$, and predicting the light
18 ball to be faster ($M = 0.94$, $SD = 0.85$), $T = 8$, $r = -.65$, were both significantly more frequent
19 than choosing the same-speed option ($M = 0.06$, $SD = 0.27$). There was significant variation
20 with age for predicting the heavy ball to be faster, $H(3) = 54.91$, $p < 0.001$, with mean scores
21 increasing with age, $J = 5875$, $z = 7.54$, $r = 0.63$. There was also significant age variation for
22 predicting the light ball to be faster, $H(3) = 54.91$, $p < 0.001$, with mean scores decreasing
23 with age, $J = 1908$, $z = -7.54$, $r = -0.63$. There was no significant interaction of age with mean
24 scores for same-speed options.
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Figure 5 shows the mean scores by age group for the incline comparisons, i.e. where the children had to compare motion down a high incline with the same ball's motion down a low incline. A maximum score of 2 was obtainable. There was a significant interaction of incline change with mean scores, $\chi^2(2, n = 144) = 50.01$, $p < 0.001$. There was no overall

1
2 significant preference for faster or slower motion as the incline changed, but both faster
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4 motion ($M = 0.89$, $SD = 1.01$), $T = 7$, $r = -0.58$, and slower motion ($M = 1.00$, $SD = 1.01$), T
5
6 = 6, $r = -0.53$, were significantly preferred over no change at all ($M = 0.11$, $SD = 0.46$). There
7
8 was no overall age variation. There were no significant differences between the heavy ball
9
10 and the light ball conditions for faster or slower motion, but there was a significant difference
11
12 for same-speed choices, where the light ball ($M = 0.25$, $SD = 0.64$) was more likely to be
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14 attributed no change in speed than the heavy ball ($M = 0.01$, $SD = 0.11$) as the incline
15
16 changed, $U = 2264$, $p < 0.05$, $r = -0.24$. The balls were correctly predicted to be faster ($M =$
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18 1.69 , $SD = 0.68$) rather than slower ($M = 0.18$, $SD = 0.54$) when the incline height was raised,
19
20 $T = 7$, $p < 0.001$, $r = -0.80$. There was no significant difference between predicting them to be
21
22 slower or unchanged. The balls were predicted to be slower ($M = 1.57$, $SD = 0.80$) rather than
23
24 faster ($M = 0.29$, $SD = 0.68$) when the incline height was lowered, $T = 6$, $p < 0.001$, $r = -0.68$.
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26 Again, there was no significant difference between predicting them to be faster or unchanged.
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28 Ball type had no significant effect on either of the incline height changes.
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32 [Insert figure 5 about here]
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36 Discussion 37 38 39

40 The results of the present study indicate that horizontal motion and vertical motion do
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42 indeed seem to be differentiated psychologically from each other, lending support to previous
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44 analyses (Hayes, 1979; Howe, 1998) and fitting into the commonsense theory offered by
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46 Ogborn and colleagues (Bliss & Ogborn, 1988; Bliss et al., 1989; Ogborn, 1985). Inverse
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48 pictures emerged for the two motion types. Faster motion along a horizontal was generally
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50 associated with lightness, on the whole consistent with previous work with children in this
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2 age range (Howe, 1991, as cited in Howe, 1998; Inhelder & Piaget, 1958). Although the
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4 results suggest stability in reasoning, qualitative changes across age groups were not
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6 considered here, and the current results are therefore only partially comparable to previous
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8 research. Faster motion in fall, on the other hand, was associated with heaviness, also
9
10 consistent with extensive previous research (Baker et al., 2009; Champagne et al., 1980, as
11
12 cited in McDermott, 1984; Chinn & Malhotra, 2002; Hast, 2011; Nachtigall, 1982; Sequeira
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14 & Leite, 1991; van Hise, 1988). Both views were held consistently across age groups.

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16 Given the literature, the *differentiation* of the horizontal and vertical dimensions need
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18 not be discussed in detail. However, Ogborn and colleagues' (Bliss & Ogborn, 1988; Bliss et
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20 al., 1989; Ogborn, 1985) account does not offer a sufficient explanation as to how the
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22 dimensions *interact* in children's understanding of motion, and therefore offers limited
23
24 guidance over motion down an incline. The present work shows that whilst the younger
25
26 children predicted faster motion down an incline for the lighter ball (as with horizontal
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28 motion), the older children typically predicted this for the heavier ball (as with vertical
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30 motion). It seems there was not a particular age point where children suddenly switched from
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32 associating faster incline motion with lightness to associating it with heaviness. Instead, a
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34 gradual change was observed, suggesting that even though the understanding changes from
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36 one incorrect view to another incorrect view, without involving same-speed predictions at all,
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38 there is little resistance to change in conceptions within the total age range. This is relevant as
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40 regards educational implications.

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42 Despite the observed shift all children seemed to understand how changing the height
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44 of an incline, and therefore changing the nature of dimension interaction and the degree of
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46 support offered by the incline, affects object motion. Similarly, they were all able to explain
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48 for the control question with the practice ball that motion down an incline can be initiated
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50 without any pushing – like in free fall. This seems to suggest that children's notion of
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2 diagonal dimensions is informed by their understanding of both horizontal and vertical
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4 dimensions at all ages, yet younger children appear to associate incline motion more with
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6 supported horizontal motion and older children integrate elements of fall more frequently into
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8 their conception of inclines, thereby reasoning similarly about those two dimensions. The
9
10 shift seems particularly puzzling considering the observation that understanding of both
11
12 horizontal and vertical motion within the present research context does not appear to change
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14 with age. So why does this conceptual shift occur?

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16 For the younger children the horizontal support was more salient. This saliency of
17
18 support is not particularly surprising. Even infants have been shown to appreciate support as
19
20 hindrance to vertical fall (Baillargeon & Hanko-Summers, 1990; Baillargeon, Needham, &
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22 DeVos, 1992; Needham & Baillargeon, 1993), and their understanding quickly becomes
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24 sufficiently refined to provide an accurate notion of what level of support is appropriate. In
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26 addition, however, Hast (2011) found that alongside the shift in incline motion predictions
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28 [the same](#) children also displayed an increasing awareness with age of acceleration down
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30 inclines. Younger children who did not show such an understanding viewed incline motion in
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32 terms of it being supported, like horizontal motion, thus aligning the two. As children gained
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34 awareness with age that acceleration (rather than deceleration, as would be the case along a
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36 horizontal) occurs down inclines like it does in fall, they shifted their alignment.

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38 It seems that the children in the present study may have been aware of a general
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40 involvement of both dimensions in incline motion, as shown by their understanding of incline
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42 changes and motion onset. Thus with an increasing level of sophistication, i.e. incorporating
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44 an awareness of speed change, and an increasing realisation about similarities between
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46 inclines and verticals on the basis of acceleration versus deceleration the saliency of support
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48 becomes void. It seems improbable that older children absolutely equate motion down
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50 inclines to fall, but clearly the vertical element becomes more important to them, since in
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2 both cases objects behave similarly regarding speed change. This highlights the possible
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4 relevance of the development of speed change awareness in developing commonsense
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6 theories of motion.
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8 The observed shift in conceptions offers new questions to investigate that may
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10 contribute to understanding this shift within the commonsense theory more clearly. A
11
12 particularly crucial question concerns the qualitative reasoning of speed, both across age
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14 groups and across task types. For instance, do children perceive the difference between the
15
16 two balls in terms of their predicted speeds down an incline to be as great as in either the
17
18 horizontal or the vertical dimension alone? Moreover, how might this change with age? Such
19
20 an in-depth understanding bears implications for conceptual change approaches. Current
21
22 approaches – despite their variety – do not seem sufficiently effective in eliciting change in
23
24 areas where conceptions are highly resistant to modification, such as dynamics. But such
25
26 conceptions need to be changed for successful subsequent learning (cf. Reif, 2008; Sherin,
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28 2006).
29

30 The results carry implications for teaching practice at different ages. By finding
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32 indications of change occurring over age where dimension interaction is concerned, the
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34 suggestion arises to put change programmes in place early, when there seems to be low
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36 resistance. In addition, by focussing on the entire motion system and the interaction of
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38 dimensions within it rather than on the distinction of dimensions it may become easier to
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40 elicit changes in the general conceptual understanding of object motion.
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42 It is evident that children are able to distinguish between horizontal and vertical
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44 dimensions early on. Yet the National Curriculum for England, Wales and Northern Ireland
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46 (DfEE, 1999), for instance, which is the curriculum relevant to the sample in the present
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48 study, states that children aged 5 to 7 years should be taught about elements relating to
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50 motion along the horizontal and children aged 8 to 12 years about gravity and air resistance in
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2 fall. In Scotland, no official specific guidelines currently exist regarding topics to be taught,
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4 but recommendations in place (e.g. SSERC, 2009) follow a very similar approach. There is
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6 no indication concerning teaching about motion down inclines. Teaching practice should first
7
8 focus directly on the *distinction* between horizontal and vertical dimensions. Following from
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10 this, alongside the development of awareness of speed change teaching should focus on the
11
12 *integration* of dimensions and help construct a complete and accurate theory of motion by the
13
14 end of the primary school age.

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16 In summary, the study indicates not only how horizontal and vertical motion
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18 dimensions are psychologically differentiated from each other but also how at the same time
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20 they interact with each other in children's reasoning. It contributes to children's
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22 commonsense theory of motion as it currently stands in the literature. It is suggested that the
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24 relation between the two psychologically distinguished motion dimensions is only beginning
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26 to be understood and that the growing ability to integrate information successfully needs to be
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28 considered, both in theoretical models and in its applications to educational practice.

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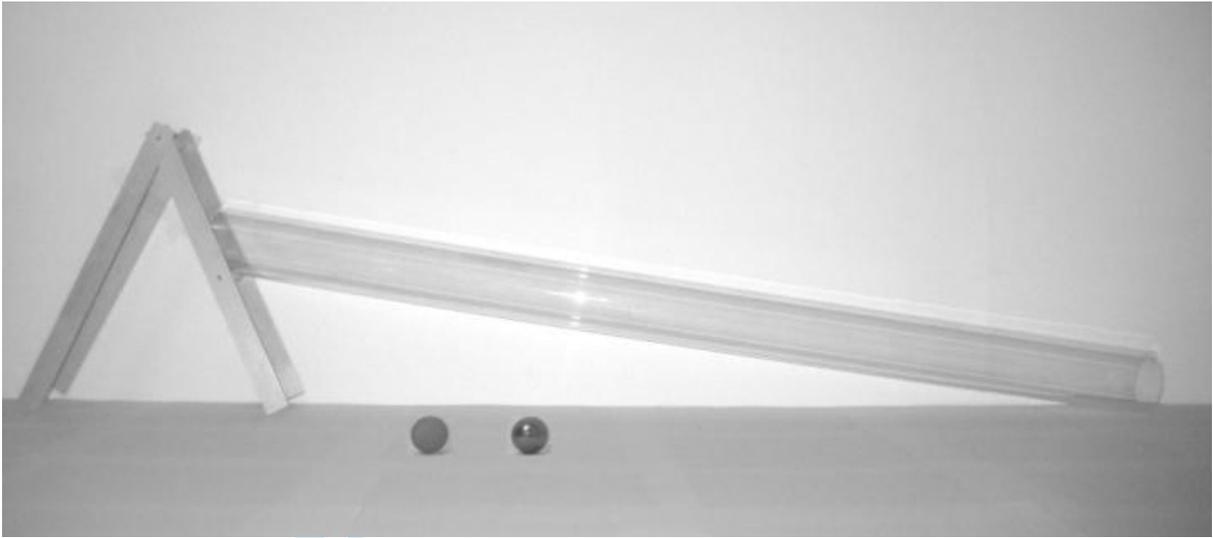
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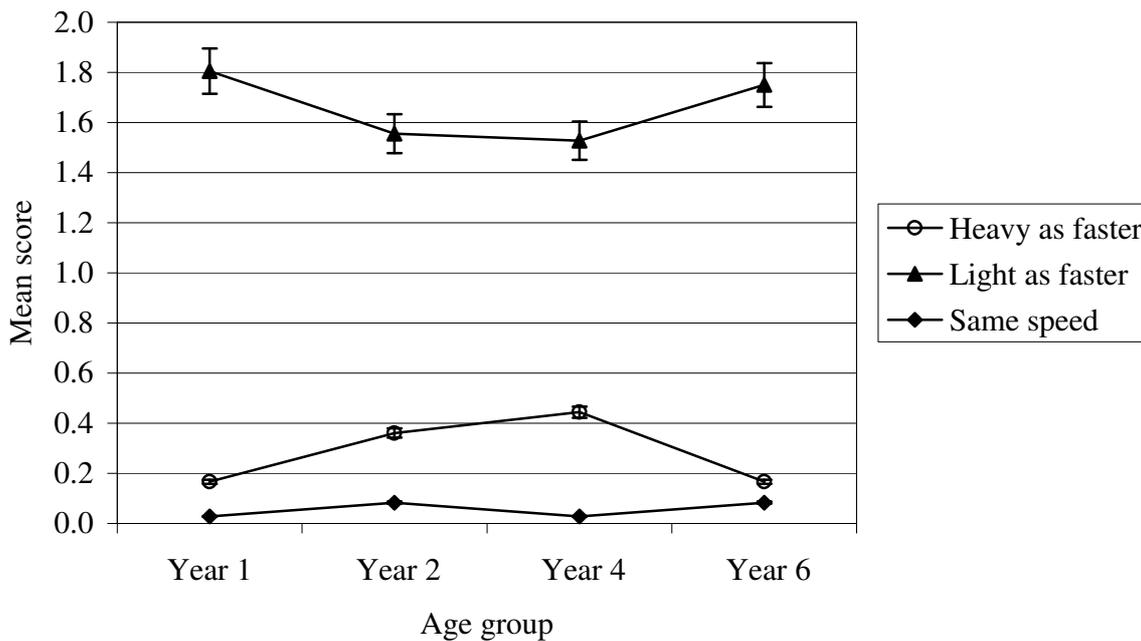
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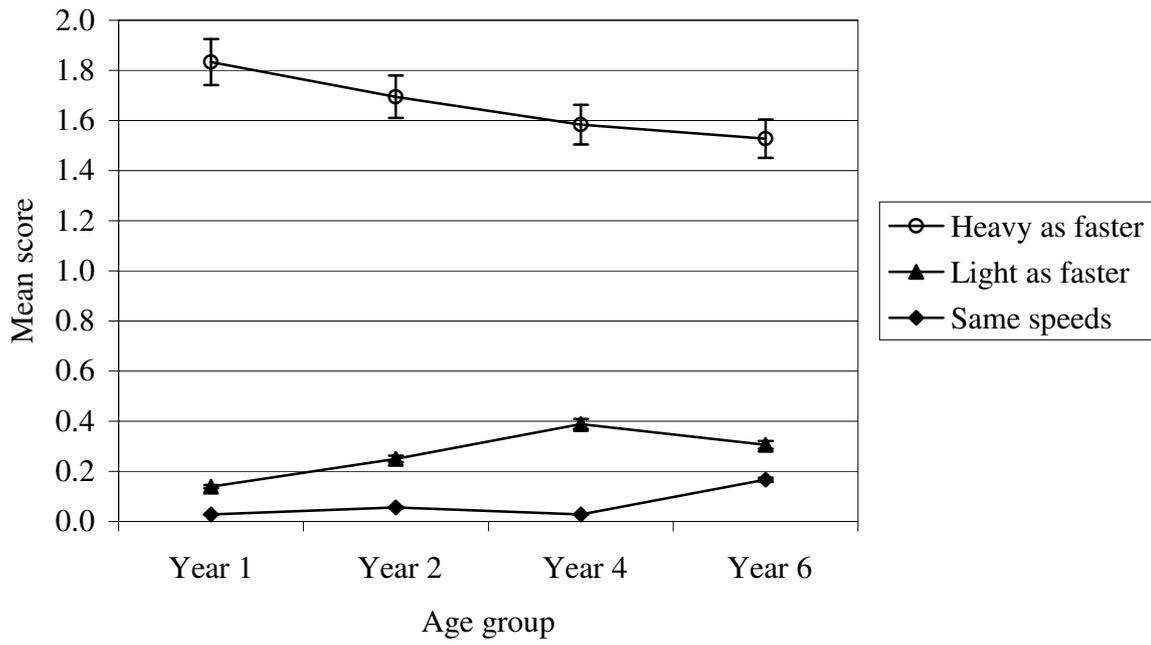
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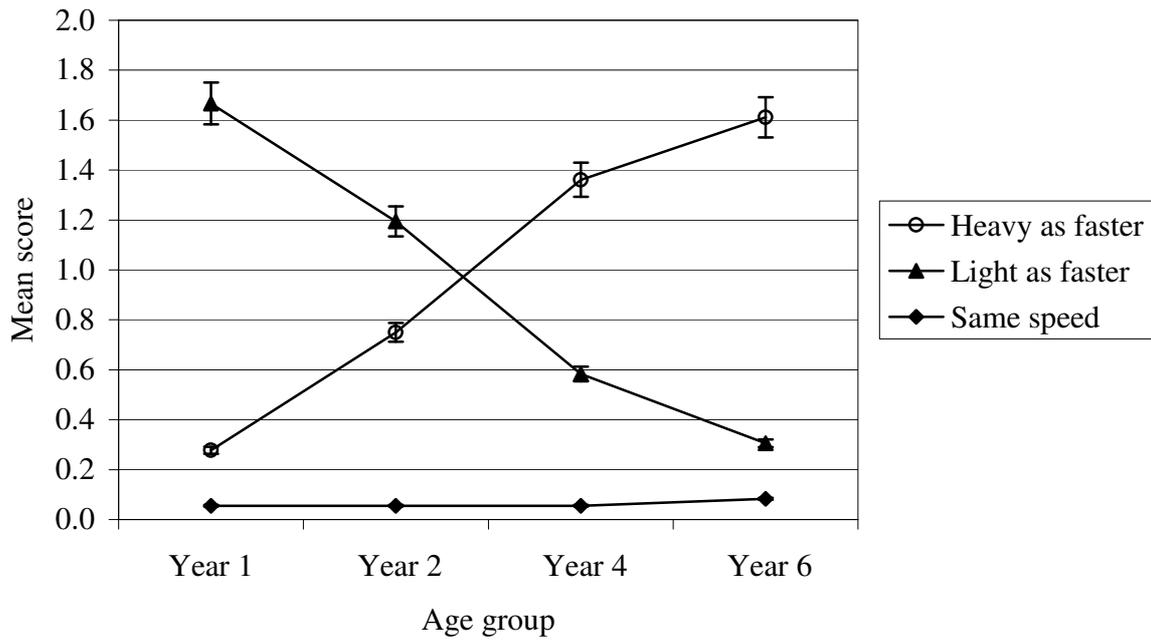
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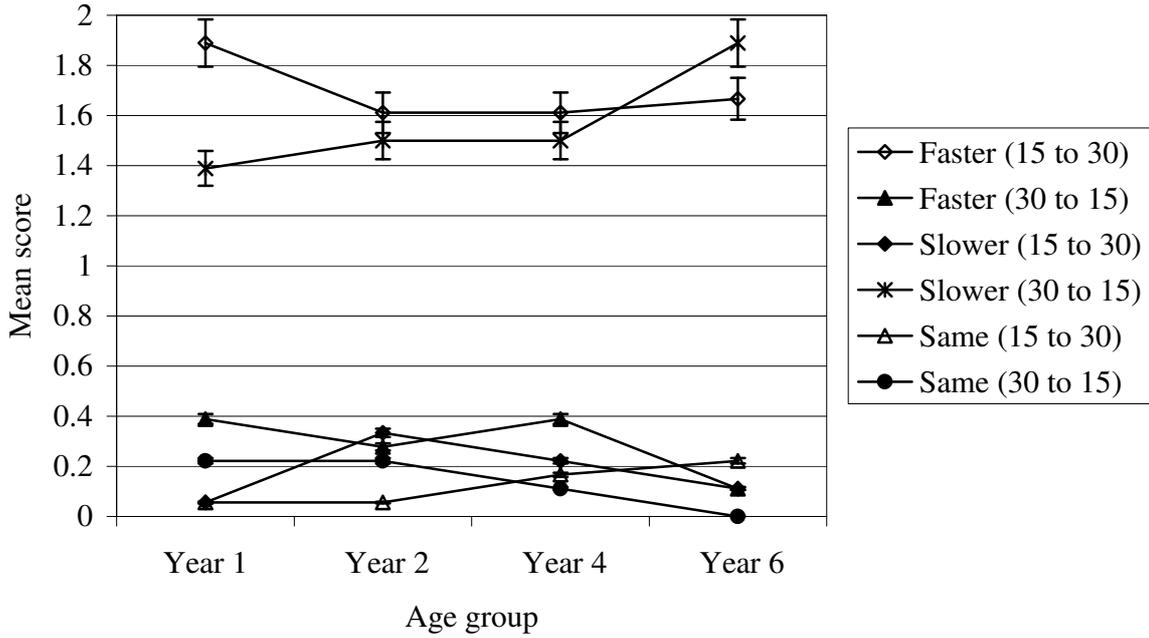


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Section	Questionnaire							
	1	2	3	4	5	6	7	8
1	Incline at 15cm (both balls)	Incline at 30cm (both balls)	Incline at 30cm (both balls)	Incline at 30cm (both balls)	Fall (both balls)	Fall (both balls)	Fall (both balls)	Fall (both balls)
	1 practice question, 2 test questions							
2	Incline at 30cm (both balls)	Incline at 15cm (both balls)	Incline at 30cm (both balls)	Incline at 30cm (both balls)	Incline at 30cm (both balls)			
	2 test questions	2 test questions	2 test questions	2 test questions	1 practice question, 2 test questions	1 practice question, 2 test questions	1 practice question, 2 test questions	1 practice question, 2 test questions
3	Horizontal (both balls)	Horizontal (both balls)	Horizontal (both balls)	Horizontal (both balls)	Incline at 30cm (both balls)	Incline at 30cm (both balls)	Incline at 15cm (both balls)	Incline at 15cm (both balls)
	1 practice question, 2 test questions	2 test questions	2 test questions	2 test questions	2 test questions			
4	Fall (both balls)	Fall (both balls)	Fall (both balls)	Fall (both balls)	Horizontal (both balls)	Horizontal (both balls)	Horizontal (both balls)	Horizontal (both balls)
	1 practice question, 2 test questions							
Comparison ball	Heavy	Light	Heavy	Light	Heavy	Light	Heavy	Light