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Adults see vision to be more informative than it is

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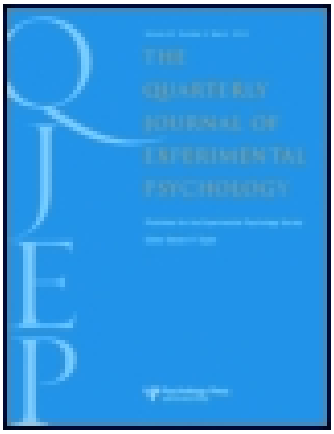

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Adults see vision to be more informative than it is

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Humans gain a wide range of knowledge through interacting with the environment. Each aspect of our perceptual experiences offers a unique source of information about the world—colours are seen, sounds heard and textures felt. Understanding how perceptual input provides a basis for knowledge is thus central to understanding one's own and others' epistemic states. Developmental research suggests that 5-year-olds have an immature understanding of knowledge sources and that they overestimate the knowledge to be gained from looking. Without evidence from adults, it is not clear whether the mature reasoning system outgrows this overestimation. The current study is the first to investigate whether an overestimation of the knowledge to be gained from vision occurs in adults. Novel response time paradigms were adapted from developmental studies. In two experiments, participants judged whether an object or feature could be identified by performing a specific action. Adult participants found it disproportionately easy to accept looking as a proposed action when it was informative, and difficult to reject looking when it was not informative. This suggests that adults, like children, overestimate the informativeness of vision. The origin of this overestimation and the implications that the current findings bear on the interpretation of children's overestimation are discussed.

Keywords: Theory of mind; Source of knowledge; Aspectuality; Epistemic mental state; Folk psychology

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Reasoning about epistemic states is a key process that guides social behaviour. One crucial component of epistemic reasoning concerns *how* knowledge about the world is acquired. In particular, how knowledge is gained from interacting with the world. For example, someone who looks at a cup of tea perceives the colour of the brew, whereas someone who touches the same cup perceives the temperature of the tea. This *source of knowledge reasoning* provides a link between perceptual experiences and the ensuing knowledge that is gained (O'Neill, Astington, & Flavell, 1992; Pillow, 1989; Robinson, Thomas, Parton, & Nye, 1997). Linking perceptual access with subsequent knowledge is not only crucial for understanding our own epistemic states (Perner & Ruffman, 1995), but it is also an essential feature of understanding other people's epistemic states. Despite the clear relevance that source of knowledge reasoning has in diverse areas of research (e.g., theory of mind, metacognition and episodic memory), as well as real-life social interactions, little is known

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about the way in which adults engage in such reasoning.[1]

The majority of prior research has focused on the developmental trajectory of source of knowledge reasoning and we first turn to this existing literature. A number of studies suggest that between 2½ and 5 years of age, children learn about the causal relationships between the world and their own minds, as well as others' minds. Around 2½ to 3 years of age, children start to relate their own visual experience with knowledge (Call & Carpenter, 2001) and only attribute knowledge to people performing perceptual acts, not to those performing non-perceptual acts (Pillow, 1989, 1993). By the age of 4, their understanding of the specific experiences gained from different perceptual access to the world improves significantly (hereafter referred to as understanding of *aspectuality*, O'Neill & Chong, 2001). For example, 4-year-olds are better than 3-year-olds at specifying the correct action that allows them to verify whether an object has a specific property (for instance, finding out if a glass of water contains sugar or not, finding out if a ball is red or green). By the age of 5, children are close to the developmental endpoint of understanding aspectuality (O'Neill et al., 1992; Pillow, 1993), but, as we summarize below, they are still not flawless when judging the knowledge to be gained from looking (O'Neill et al., 1992; Robinson et al., 1997).

Robinson et al. (1997) suggest that children at 5 years of age overestimate the knowledge they can gain from looking. In the second experiment of this study, 5- and 8-year-olds were presented with pairs of objects that looked identical but differed in weight or sound, as well as objects that looked different but weighed or sounded the same. The experimenter covered the two objects with a cloth and removed one of the two objects out of children's sight. The experimenter asked the children to predict whether they would know which object had been chosen by just looking at the object. After the children responded, feedback was given to them. Results showed that both 5- and 8-year-olds were highly accurate in their responses when the pair of objects looked different. However, when presented with a pair of objects that looked the same but were weighted differently or sounded different, 5-year-olds carried on predicting that they would know the object's identity just by looking at it. Even following verbal feedback, children did not improve their performance.

Overestimation of knowledge gained from vision is not restricted to reasoning about one's own knowledge of the world; a similar overestimation is apparent when children reason about others' knowledge. For instance, children have the tendency to over-attribute knowledge to a person who looks at an object, but not to a person who feels the same object (O'Neill et al., 1992). In the second experiment of O'Neill et al., 3-, 4-, and 5½-year-olds were asked to judge two puppets' knowledge of a hidden object. Children chose one of two objects that either looked the same but felt different or looked different but felt the same. The chosen object was hidden inside a tunnel whilst the puppets were not looking. One puppet performed an action that allowed the identification of the hidden object (e.g., feeling a soft object), whilst the other puppet performed the alternative action (e.g., looking at the soft object). Children were asked to choose the puppet that knew about the differentiating feature of the selected object. Consistent with Pillow (1993), results showed that 3-year-olds failed to distinguish between the knowledge states of the two puppets, while 4- and 5½-year-olds were at chance when comparing knowledge states of the puppet that looked versus the puppet that felt the object. The error patterns of the 4- and 5½-year-olds showed that they failed by choosing the puppet that looked inside the tunnel as the one to know about the tactile properties of the hidden object, thus over-attributing knowledge gained through vision.

[1]Although studies on false memory (e.g., Brainerd & Reyna, 2002) showed that adult witnesses appear to confuse information sources, such as seeing something with their own eyes versus being told about an event. There is a distinction to be made between committing a mistake in remembering an information source from the past versus reasoning online about the information to be gained from a particular source at present. The current study focuses on the latter.

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It has been argued that the overestimation of the knowledge to be gained from vision is driven by children's immature understanding of knowledge sources (e.g., O'Neill et al., 1992; Robinson et al., 1997). According to this account, as older children acquire a mature source of knowledge reasoning system, they would outgrow such overestimation. An alternative is that the overestimation reflects a constant feature of source of knowledge reasoning across the lifespan. Curiously, however, there has been no investigation of the mature mental state reasoning system to verify these accounts. Solely based on evidence from developmental studies, it is not clear whether the overestimation is a result of children's immature reasoning or whether it might reflect a bias embedded in the mature source of knowledge reasoning system. There are reasons to suspect that the bias may persist into adulthood since previous studies indicate that adults show biases in their reasoning about knowledge. For example, evidence suggests that adults make biased predictions based on their own privileged knowledge, instead of a protagonist's ignorance (e.g., Birch & Bloom, 2004). Moreover, adult speakers frequently underestimate the ambiguity in their speech and overestimate the degree to which others comprehend their intention (Keysar & Henly, 2002). Therefore, even in fully developed minds it is clear that biases in reasoning about knowledge exist. Thus, we set out to examine mature source of knowledge reasoning in adulthood.

The current study employed novel response time paradigms adapted from developmental studies (O'Neill et al., 1992; Robinson et al., 1997). In two experiments, adult participants were asked to judge whether an object or an object feature can be identified by performing a given action. To ensure that any observed bias for vision is an overestimation of its informativeness and not an overestimation of participants' own ability (Keysar & Henly, 2002), the judgements participants made were about an actor. Each trial paired an actor performing one of three actions with an object or an object feature. The participants' task was to confirm or reject the informativeness of the action in relation to the object or object feature. If there is a bias to overestimate the informativeness of looking in adulthood, it should be reflected by the ease with which correct object-action pairs are accepted and the difficulty with which incorrect object-action pairs are rejected.

EXPERIMENT 1

Method

Participants

Twenty-five French-speaking undergraduate students (ten males, mean age 19 years, age range 17 to 20 years) from the Université catholique de Louvain took part in this experiment in return for course credits. An additional two participants' data were excluded prior to analysis due to having overall performance at chance level.

Design and procedure

A 3×2 within-subject design was constructed with action (look, feel, lift) and object-action congruency (congruent, incongruent) as factors. The testing session was carried out in French. The experiment involved observing interactions between an actor and an experimental device. The experimental device was explained to participants. The device consisted of two identical containers, which were positioned on a stand with two holes to hold the containers. A black cloth covered the two containers. Objects with salient features were positioned on or in the containers. An object's most salient feature determined the object's location. Objects with salient visual features were placed on top of the containers. Objects with salient textures were attached to the bottom of the containers. Objects with salient weights were placed inside the containers. Objects could only be identified by one correct action. For example, by lifting the cloth, objects with salient visual features could be identified; by reaching below and feeling the bottom of the containers, objects with salient textures could be identified; by lifting the containers, objects with salient weights could be identified. Participants were shown images of an actor performing each action with the device

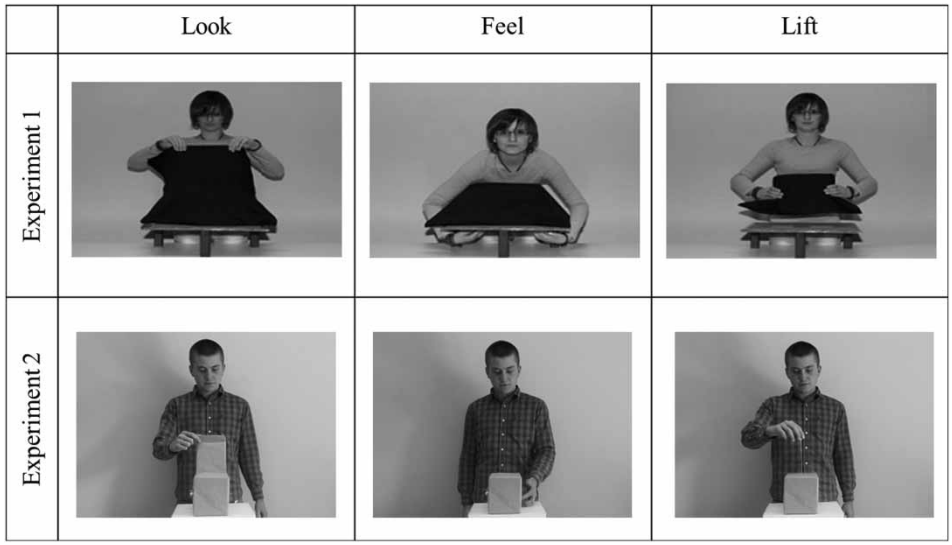

Figure 1. *Action images employed in Experiments 1 and 2.*

(Figure 1). These action images were subsequently employed in the test phase.

During the warm-up phase, the names and images of six test objects (i.e., objects that were later used in the test phase: a post-it note, a sheet of colour label stickers, a sheet of sandpaper, a cotton ball, a 5 kilogram dumbbell, a 10 pound dumbbell) along with an additional six filler objects (i.e., objects used only in the warm-up phase: a colourful postcard, a colourful business card, bubble wrap, a sponge, a weight, and a pétanque ball) were presented to the participants. Each object had a salient feature (for example, a post-it has a bright colour, a sheet of sandpaper has a rough texture, a pétanque ball is heavy) that could be known by performing one of the three actions. Each action was relevant for identifying two test objects and two filler objects (looking was associated with the post-it, the colour-labelled stickers, the colourful postcard and the colourful business card; feeling was associated with the sandpaper, the bubble wrap, the sponge and the cotton ball; weight was associated with the two dumbbells, the weight and the pétanque ball). To ensure that the designated object categories were consistent with participants' object categorization, participants were required to categorize the objects according to their most salient features: visual feature, texture, or weight. All participants correctly categorized the objects. Finally, the action images were shown to participants and all participants correctly named the actions.

The warm-up phase was followed by a test phase, where participants underwent a computer-based task. During the test phase, participants made judgements about the three actions (look, feel, lift), which were performed to identify the six test objects (post-it note, colour label stickers, sandpaper, cotton, 5 kilogram dumbbell, 10 pound dumbbell). Each trial began with a fixation cross (500 ms), followed by the visual presentation of an object (1000 ms). Subsequently, an image of one of the three actions was shown, above which a question read "Peut-elle le trouver? (*Can she find it*?)". The action image remained on the screen until a response was detected or for 5000 ms, during which time participants judged whether the actor could identify the object by performing the action shown (see Figure 2). Participants engaged in yes-no responses by left-clicking on the computer mouse for "yes", and right-clicking for "no".

A total of 144 trials were presented in three test blocks of 48 trials. All trials were presented in a

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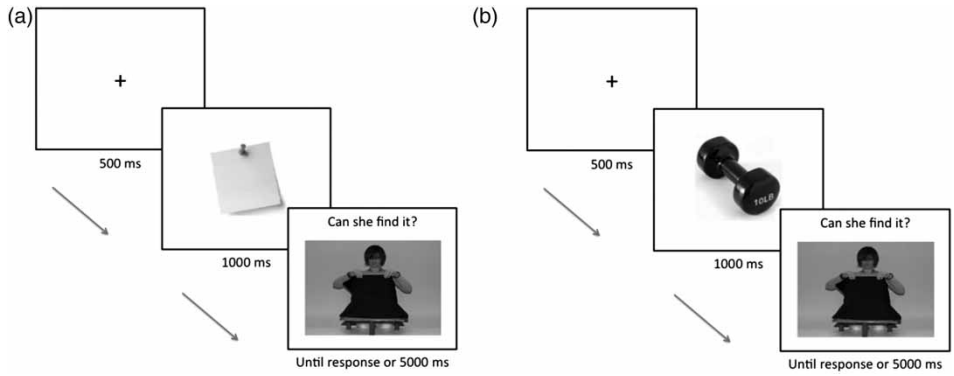

Figure 2. *Trial sequence (translated into English) in Experiment 1: (a) shows a trial from the look-congruent condition, (b) shows a trial from the look-incongruent condition.*

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random order. Participants completed an additional 12 practice trials prior to the test trials in order to familiarize themselves with the trial sequence. Feedback was given on the computer screen immediately after each practice trial to ensure that the participants fully understood the task. The experiment was presented with E-prime (Schneider, Eschman, & Zuccolotto, 2002a, 2002b). Response time (RT) and accuracy on each trial were measured. RTs were measured from the onset of the action images and accuracy was calculated in a binary manner (correct or incorrect).

Data analysis

We submitted the RT data from each condition to a 3×2 repeated measures analysis of variance (ANOVA) with action (look, feel, lift) and object-action congruency (congruent, incongruent) as factors. Where an interaction effect was found to be significant, we then calculated the congruency score for each action condition. This was done by deducting the RT in the congruent condition from that in the incongruent condition. The congruency score offers a summary of the ease with which congruent object-action pairs were accepted and the difficulty with which incongruent object-action pairs were rejected. It is important to note that the congruency score represents the absolute difference between the congruent and incongruent conditions within each action condition. This difference is contingent on the overall speed to which an action condition was responded. In order to account for this variance, which is independent of the congruency scores, we scaled the congruency scores to the overall speed of responses in each action condition. This was achieved by dividing the congruency score in each action condition by the sum of the incongruent and congruent conditions from the same action condition. More specifically, the formula employed to calculate the scaled congruency scores was (incongruent condition − congruent condition) ÷ (incongruent condition + congruent condition). The scaled congruency score in the look condition was compared to those in the lift condition and the feel condition, respectively. A bias to overestimate the informativeness of vision is likely reflected in a disproportionately larger scaled congruency score.

Results

Error analysis

Response errors comprised 4.32% of the total trials and no timeout errors occurred. A 3×2 repeated measures ANOVA was conducted on error rate with action (look, feel, lift) and object-action congruency (congruent, incongruent) as factors. There were no significant main effects of action, $F(2, 48) = 1.13$, $MSE = 0.004$, $p = .330$, $\eta p^2 = .045$, or object-action congruency, $F(1, 24) = 0.19$, $MSE = 0.002$, $p = .671$, $\eta p^2 = .008$,

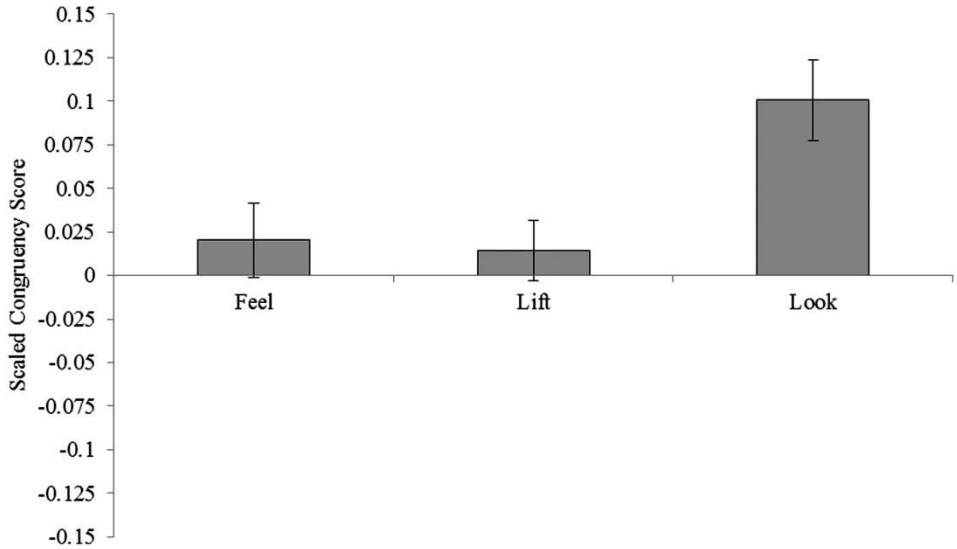

Figure 3. *Experiment 1 results: Average scaled congruency score in Experiment 1 as a function of action type. Error bars show standard errors.*

and no significant interaction between action and object-action congruency, $F(2, 48) = 0.95$, $MSE = 0.004$, $p = .394$, $\eta p^2 = .038$.

Response time analysis

Erroneous responses were removed from further analysis. Responses with RT beyond 2500 ms (0.61% of the data) were excluded from the analysis to correct for the positive skew in the overall data distribution. A 3 × 2 ANOVA was conducted on RT with action (look, feel, lift) and object-action congruency (congruent, incongruent) as factors. There was a significant main effect of action, $F(2, 48) = 3.64$, $MSE = 9232.48$, $p = .034$, $\eta p^2 = .132$, with the RT associated with the feel condition (814.75 ms) being slower than that of the lift condition (769.26 ms) and the look condition (770.44 ms), respectively. There was also a significant main effect of object-action congruency, $F(1, 24) = 23.23$, $MSE = 5495.51$, $p < .001$, $\eta p^2 = .492$, with the RT associated with the congruent condition (755.65 ms) being faster than that of the incongruent condition (813.99 ms). The interaction effect between action and object-action congruency was also significant, $F(2, 48) = 4.42$, $MSE = 8145.13$, $p = .017$, $\eta p^2 = .155$. This interaction effect was further examined by analysing the scaled congruency score for each action condition.

The one-way ANOVA conducted on the scaled congruency scores with action (look, feel, lift) as the factor showed a significant main effect of action, $F(2, 48) = 4.46$, $MSE = 0.013$, $p = .017$, $\eta p^2 = .157$(see Figure 3). The look condition showed a significantly higher scaled congruency score compared to the lift condition, $t(24) = -2.93$, $p = .007$.[2] The look condition showed a marginally significantly higher scaled congruency score than the feel condition, $t(24) = -2.14$, $p = .042$. Participants were quicker to accept congruent object-action pairs and hesitated longer to reject incongruent object-action pairs when the action proposed was *look* compared to lift and feel. There was no difference between the scaled congruency scores in the feel condition and the lift condition $t(24) = 0.20$, $p = .844$.

One could argue that objects with salient visual features are easier to process and therefore induced globally quicker responses compared to objects with salient texture and weight features. This would lead

[2]Bonferroni correction was applied for multiple comparisons; corrected significance level was .017.

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to quicker responses to all items of the look-congruent condition, half of the items of the lift-incongruent condition, and half of the items of the feel-incongruent condition. Should this be the case, the larger congruency score in the look condition compared to the lift and feel conditions would not be a signature of a bias to overestimate the informativeness of vision but would be an artefactual effect. To test this account, we compared the RTs of trials within the lift-incongruent condition that presented objects with salient texture to those that presented objects with salient visual features. No difference in RTs was found, $t(24) = 1.23$, $p = .232$. The RTs of trials within the feel-incongruent condition that presented objects with salient weight and those that presented objects with salient visual features were also compared to each other. Again, no difference in RTs was found, $t(24) = 0.58$, $p = .570$. The look-congruent condition was not informative in testing this account, as differences in RTs amongst the congruent conditions were confounded with the speed to recognize the action images. The current results suggest that the congruency score in the look condition cannot be explained by a faster processing of the objects from the salient visual features category than the objects from the other two categories.

Discussion

The present findings show a larger congruency score in the look condition compared to the lift and feel conditions. The congruency score in the look condition reflects relatively facilitated responses to accepting *looking* for the congruently paired objects, whilst delayed responses to rejecting *looking* for the incongruently paired objects. Additional analysis ruled out the alternative account of an object-driven processing strategy. The current findings suggest that adults, like children, have a tendency to overestimate the informativeness of *looking* when making links between perceptual features of objects and the knowledge to be gained from looking.

One argument against our interpretation is that real objects have many features and hence they can often be identified using modes of access other than the most salient one. For example, although a dumbbell's most salient feature is its weight, its shape can also be diagnostic and this information is frequently accessed through looking. Even though participants agreed with the object categories in the warm-up phase of the experiment, this may not have prevented them from having associated the objects with more than one of the three actions when performing the task. One could further argue that since all objects were presented visually, participants necessarily relied on the objects' visual features to identify them. Hence the *actual* informativeness of vision in the current experiment could account for the *overestimation* of its informativeness. To examine this account, a new paradigm was employed in Experiment 2.

EXPERIMENT 2

In this experiment, we aimed to replicate the effect that indicates a bias to overestimate the informativeness of vision with a different paradigm. The new paradigm rules out a number of low-level accounts for such a bias by differentiating itself from the paradigm employed in Experiment 1 in the following ways. First, we removed the visual presentation of objects so that any effects observed could no longer be explained by reliance on vision to perceive the objects during the task. Second, participants were asked to judge whether an action allows identification of a specific perceptual feature rather than an object. Explicitly judging a target perceptual feature eliminated the possibility to associate object features with more than one mode of access in object identification. Third, we reversed the order of the action-object link to investigate whether the bias for vision is restricted to having an action or the knowledge to be gained as the initial input. With the reversed action-object link, we were also able to rule out effects that are solely driven by judging action images.

Method

Participants

Twenty-four French-speaking students (ten males, mean age 23.5 years, age range 18 to 45 years) from the Université catholique de Louvain took part in this experiment in return for a small honorarium. None of these participants took part in Experiment 1. An additional two participants' data were excluded prior to the analysis due to having overall performance at chance level.

Design and procedure

A 3×2 within-subject design was constructed with action (look, feel, lift) and action-object feature congruency (congruent, incongruent) as factors. In the current design, we employed a new device and a new set of objects. The objects were no longer differentiated by textures, as textures can often be identified by both vision and touch. Instead, we used *temperature* as a new differentiating feature for objects in the feel condition.

The testing session was carried out in French. The design of the experimental device was explained to the participants as follows. There are eight objects of identical shape. The objects only vary from each other in the following aspects: colour, temperature and weight. The objects could be green or white; cold or warm; light or heavy. Each object has three key features, one from each of the three aspects. The objects are placed inside an opaque box. To look at an object inside the box, one can raise the lid of the box and see the object through a window. It is not possible to feel or lift the object whilst looking at it. To feel an object inside the box, the finger hole on one side of the box can be utilized. It is not possible to look at or lift an object whilst feeling it. To lift an object inside the box, a string attached to the object can be lifted from the top side of the box. It is not possible to feel or look at an object whilst lifting it. The images of an actor performing these actions were shown to the participants as the device was being explained to them (see Figure 1). These action images were subsequently employed in the test phase. All six object features were seen equally frequently (see Table 1).

Table 1. *List of objects shown to participants in Experiment 2*

	Colour	*Temperature*	*Weight*
Object 1	Green	Cold	Light
Object 2	Green	Cold	Heavy
Object 3	Green	Warm	Light
Object 4	Green	Warm	Heavy
Object 5	White	Cold	Light
Object 6	White	Cold	Heavy
Object 7	White	Warm	Light
Object 8	White	Warm	Heavy

Note: The exact French words employed were *vert* (green), *blanc* (white), *froid* (cold), *chaud* (warm), *léger* (light), and *lourd* (heavy).

During the test phase, participants underwent a computer-based task. Each trial began with a fixation cross (500 ms), followed by one of the three aforementioned action images (2000 ms). This was followed by a sentence that read "sait-il si l'objet est (*Does he know if the object is*)" presented for 2000 ms. Finally, a feature word specifying either a colour, temperature or weight remained on screen until a response was detected or for 2500 ms, during which time participants judged whether the actor was able to obtain knowledge about the specified object feature by performing the action shown (see Figure 4). Participants engaged in yes-no responses by left-clicking on the computer mouse for "yes", and right-clicking for "no".

A total number of 144 trials were presented in three test blocks of 48 trials. All trials were presented in a random order. Feedback was given on the computer screen after participants responded to each trial. The participants in Experiment 1 received feedback during the practice trials but not during the test trials. The low error rates indicate that participants did comprehend the task. However, we felt it was important for the participants to know that they were performing correctly so that they would have the confidence to speed up their responses. The experiment was presented with E-prime (Schneider et al., 2002a, 2002b). RT and accuracy on each trial were measured. The RTs were measured from the onset of the feature words and accuracy was calculated in a binary manner (correct or not).

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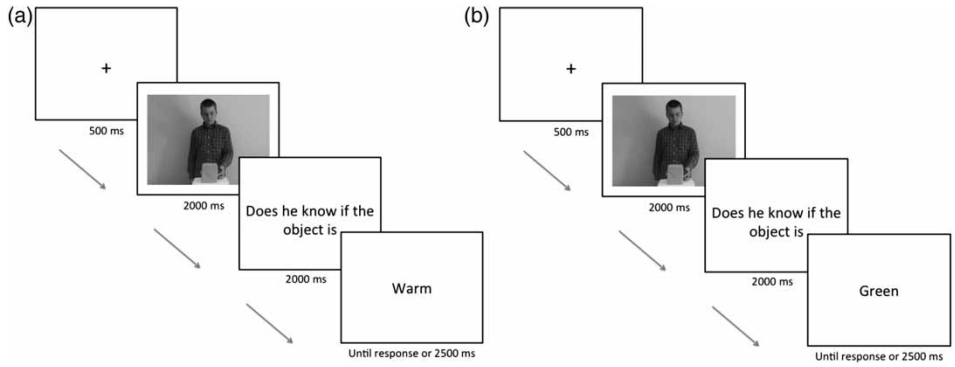

Figure 4. *Trial sequence (translated into English) used in Experiment 2: (a) shows a trial from the feel-congruent condition, (b) shows a trial from the feel-incongruent condition.*

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Results

Error analysis

Response errors (5.40%) and timeout errors (1.75%) were a small proportion of total trials. A 3 × 2 ANOVA was conducted on error rate with action (look, feel, lift) and action-object feature congruency (congruent, incongruent) as factors. There were no significant main effects of action, $F(2, 46) = 1.51$, $MSE = 0.002$, $p = .232$, $\eta p^2 = .061$, or action-object feature congruency, $F(1, 23) = 0.04$, $MSE = 0.003$, $p = .838$, $\eta p^2 = .002$, and no significant interaction effect between action and action-object feature congruency $F(2, 46) = 0.16$, $MSE = 0.003$, $p = .850$, $\eta p^2 = .007$.

Response time analysis

Response errors and timeout errors were removed from the data set. No additional data point was excluded from the analysis as there was no need to correct for the overall data distribution. A 3 × 2 ANOVA was conducted on RT with action (look, feel, lift) and action-object feature congruency (congruent, incongruent) as factors. There was a significant main effect of action, $F(2, 46) = 12.63$, $MSE = 5041.27$, $p < .001$, $\eta p^2 = .355$, with the RT associated with the feel condition (800.62 ms) being slower than that of the lift condition (748.54 ms) and the look condition (730.46 ms) respectively. There was also a significant main effect of action-object feature congruency, $F(1, 23) = 43.68$, $MSE = 5949.73$, $p < .001$, $\eta p^2 = .655$, with the congruent condition (717.39 ms) being quicker than the incongruent condition (802.36 ms). And there was a significant interaction effect between action and action-object feature congruency, $F(2, 46) = 6.01$, $MSE = 1853.20$, $p = .005$, $\eta p^2 = .207$.

The one-way ANOVA conducted on the scaled congruency scores with action (look, feel, lift) as the factor showed a significant main effect of action, $F(2, 46) = 6.69$, $MSE = 0.001$, $p = .003$, $\eta p^2 = .225$(see Figure 5). The look condition showed a significantly higher scaled congruency score compared to the lift condition, $t(23) = -3.12$, $p = .005$.[3] The scaled congruency score in the look condition was marginally significantly higher than the feel condition, $t(23) = -1.93$, $p = .066$. Participants' response pattern was consistent with that predicted by a bias to overestimate the informativeness of *looking*. Interestingly, there was also a marginally significant difference between the scaled congruency scores in the feel condition and the lift condition, $t(23) = 2.19$, $p = .039$. The trend for a significant difference between the lift and the feel conditions indicates that the informativeness of touch might also be overestimated in this experiment.

[3]Bonferroni correction was applied for multiple comparisons; corrected significance level was .017.

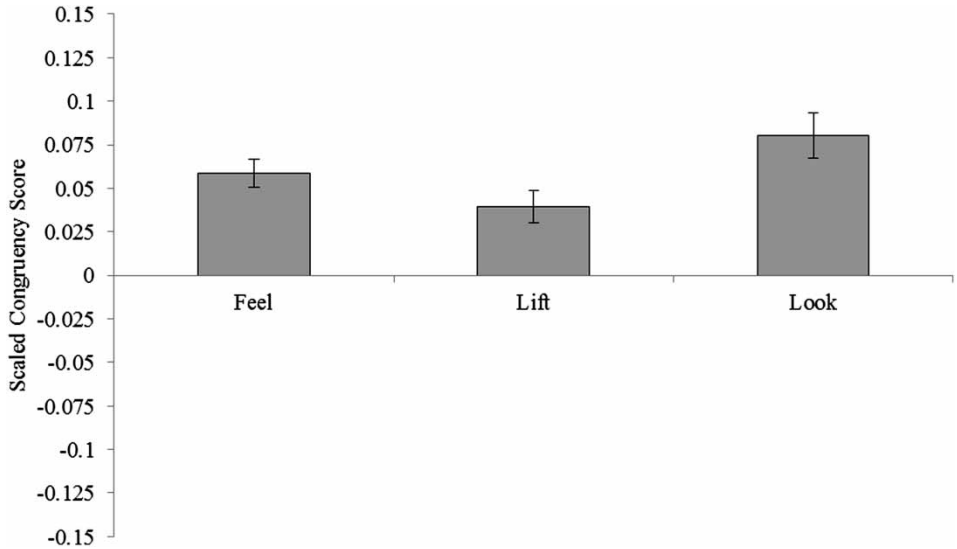

Figure 5. *Experiment 2 results: Average Experiment 2 scaled congruency score as a function of action type in Experiment 2. Error bars show standard errors.*

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One could argue that the bias to overestimate the informativeness of vision merely arose from differences in the response speed to feature words. For instance, quicker responses to colour words compared to the weight and temperature words could account for the larger scaled congruency score in the look condition compared to the lift and the feel conditions. To test this account, we compared the RTs of trials within the lift-incongruent condition that presented temperature words to those that presented colour words. No difference was observed in RTs, $t(23) = 0.86$, $p = .402$. The RTs of trials within the feel-incongruent condition that presented weight versus colour words were also compared to each other, and no difference was observed either, $t(23) = 1.60$, $p = .123$. (The look-congruent condition was not informative in testing this account, as differences in RTs amongst the congruent conditions were confounded with the speed of feature word recognition.) Thus, the current results suggest that the large scaled congruency score in the look condition cannot be accounted for by differences in the speed of feature word recognition.

We also analysed the bias for touch in the same manner. Differences within the look-incongruent condition and the lift-incongruent conditions were also further analysed using the aforementioned comparisons. There was no difference between the RTs for the weight and the temperature words in the look-incongruent condition, $t(23) = 1.26$, $p = .220$, or between the RTs for the temperature and the colour words in the lift-incongruent condition, $t(23) = 0.86$, $p = .402$. Therefore, the trend for a bias to overestimate the informativeness of touch cannot be merely driven by the speed of feature word recognition.

Discussion

The current experiment showed a larger scaled congruency score in the look condition compared to the lift and feel conditions. This disproportionately large difference between the congruent and incongruent conditions indicates a bias to overestimate the informativeness of vision. Participants were quick to accept object feature words that were congruently paired with looking, but slow to reject feature words that were incongruently paired with looking. This was a close replication of the findings from Experiment 1. This replication suggests that the bias to overestimate the informativeness of vision does not depend on a particular directionality in

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reasoning (i.e., whether the initial input is an action or the knowledge to be gained). Additionally, by employing a different paradigm from Experiment 1, we eliminated a number of low-level accounts for this effect. Participants never saw images of the objects, which removes the possibility that the effects observed in Experiment 1 were caused by a reliance on vision to perceive the images of objects. Relatedly, explicit nomination of the target object features through text did not eliminate the bias to overestimate the informativeness of vision. This finding lends no support to the suggestion that the bias for vision observed in Experiment 1 came from the competition of other unintended object features and modes of access. Taken together, Experiments 1 and 2 showed that the bias to overestimate the informativeness of vision seems robust and survives the changes of the superficial features of the two paradigms.

In addition to the bias to overestimate the informativeness of vision, there was also a trend towards a bias to overestimate the informativeness of touch. This finding is consistent with some previous developmental studies. These studies suggest that in certain circumstances, children choose touch, rather than vision, as their preferred mode of access for identifying an object (O'Neill et al., 1992; Robinson, Haigh, & Pendle, 2008). In other circumstances, children chose equally between vision and touch (Waters & Beck, 2009, 2012). It is noteworthy that all of these developmental studies showed that different task contexts can lead to either biases for different modes of access or no particular bias for vision or touch. It is likely that one or more of the changes made in the current design provided an appropriate context for the bias to overestimate the informativeness of touch to become observable. The specific contexts in which biases for vision and touch are likely to be observed will be discussed in the General Discussion.

GENERAL DISCUSSION

Evidence from developmental studies suggests that children overestimate the knowledge to be gained from looking (e.g., O'Neill et al., 1992; Robinson et al., 1997). The present study investigated whether a similar bias for vision can be observed in the mature mental state reasoning system. Two experiments showed that when adults reason about others' knowledge, they are biased to overestimate the informativeness of vision. This was shown in the speeded responses in accepting the objects and object features that were congruently paired with looking, and increased hesitation in rejecting the objects and object features that were incongruently paired with looking. The present study is the first to show that adults, like children, have a tendency to overestimate the informativeness of vision.

Origin of the overestimation of the informativeness of vision in children

The findings that children overestimate the informativeness of vision have been interpreted as consequences of immature reasoning capacity (O'Neill et al., 1992; Pillow, 1993). It has been proposed that the errors children make on source of knowledge tasks reflect conceptual limitations (Gopnik & Graf, 1988) in the understanding of how beliefs and representations about the world causally relate to the world itself (O'Neill et al., 1992). For example, when a 4-year-old wrongly judges that information about the softness of an object can be gained from looking at it, he/she would be deemed to lack concepts of the correct correspondence between various actions and the kind of knowledge that can be gained from these actions. The current finding that adults are also biased to overestimate the informativeness of vision weakens the conceptual limitation account as the sole account for children's difficulties. From the high accuracies across all conditions, it is clear that adults have the requisite source of knowledge concepts. Hence this bias for vision in adults likely reveals a limitation in *knowledge-use*, rather than a limitation in conceptual knowledge per se.

An analogical demonstration of adults' limitation in *using* acquired concepts comes from studies which suggest that adults who have

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mature theory of mind abilities nevertheless frequently fail to take others' perspectives into account (Apperly et al., 2010; Birch & Bloom, 2004; Keysar, Lin, & Barr, 2003). Epley, Morewedge, and Keysar (2004) indicate that adults and children show highly similar egocentric tendencies (i.e., quick initial looking towards an unintended/egocentric object) in a communication task. However, adults are more able than children to correct themselves and look at the intended/non-egocentric object. In line with this finding, Dumontheil, Apperly, and Blakemore (2010) showed that the ability to efficiently overcome egocentric bias improves considerably from childhood to late adolescence. Crucially, these theory of mind studies demonstrate that although the ability to efficiently overcome egocentric bias improves with age, adults do not completely outgrow egocentric tendencies. Hence, egocentrism is constantly observed in adults' theory of mind use. Here we propose that a comparable account may explain adults' bias in source of knowledge reasoning, such that the bias to overestimation of the informativeness of vision exists even in the mature source of knowledge reasoning system but that adults simply benefit from better executive abilities to efficiently correct themselves. The current finding thus demonstrates that limitations in knowledge-use rather than (or in addition to) conceptual limitations are at the origin of the overestimation of the informativeness of vision in childhood.

Overestimation of the informativeness of touch

Experiment 2 showed that in addition to a bias for vision, adults also have a tendency to overestimate the informativeness of touch. Prior evidence suggests that different task contexts can lead to biases for different modes of access, including both vision and touch (O'Neill et al., 1992; Robinson et al., 2008). To our knowledge, O'Neill et al. was the only other study to demonstrate biases to overestimate the informativeness of both vision and touch. O'Neill et al. argued that children were likely to show a preference to feel an object when the judgements concerned themselves, as this is consistent with their daily experience. When children were asked to attribute knowledge to others, they were likely to choose the person who looked, as children often observe that the person who looks obtains information about the environment. Whilst this explanation may account for the biases observed in O'Neill et al., it cannot explain the biases found in the current study, since the bias to overestimate the informativeness of touch was shown when adult participants made judgements about an actor.

It is noteworthy that in O'Neill et al. (1992), the judgements for self always coincided with children lacking knowledge about the hidden object's identity, and that the judgements for others coincided with children knowing the hidden object's identity. We suggest that a bias for vision can be observed both when the object identity is known (e.g., Experiment 1 of the current study; Experiments 2 and 3 of O'Neill et al.) and when it is unknown (e.g., Experiment 2 of the current study; Experiment 2 of Robinson et al., 1997). On the other hand, a bias to overestimate the informativeness of touch is likely driven by the lack of knowledge about the object's identity (e.g., Experiment 2 of the current study; Experiment 1 of O'Neill et al.; Experiment 2 of Robinson et al., 2008). One potential explanation for the bias to overestimate the informativeness of touch to only occur under such a condition is that in our daily experience we obtain much information about an unknown object by feeling it (or to be precise, *feeling it whilst looking at it*). Although as previously mentioned, vision often allows us to identify known objects and their textures without even feeling the objects, we do often explore unknown objects by making physical contact with them. Hence the observed bias to overestimate the informativeness of touch may be caused by lacking of knowledge about objects' identity. To clarify, we do not claim that the presentation of unknown objects guarantees that a bias for touch will occur. Nonetheless, not knowing objects' identities is likely to be a prerequisite to showing a bias to overestimate the informativeness of touch.

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Conclusion

Across two experiments we showed that adults have a tendency to overestimate the informativeness of vision when making simple source of knowledge judgements. This bears a close resemblance to the biases observed in children (O'Neill et al., 1992; Robinson et al., 1997). We also found a trend that indicates overestimation of the informativeness of touch when adults have little knowledge about the objects' identities. Both of these biases reveal imperfection in the mature mental state reasoning system, which carries implications on the interpretations offered by previous developmental studies to explain imperfections in children's mental state reasoning system. In particular, it shows that children's errors cannot solely be accounted for by conceptual limitations but originate, at least partly, from the same biases that adults need to overcome. Further examinations into how our interactions with the world shape our reasoning about the knowledge that we gain from these interactions are necessary for a complete account of the cognitive characteristics of source of knowledge reasoning.

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