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Metacognition of agency across the lifespan

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ABSTRACT

Metacognitions of agency were investigated using a computer task in which X's and O's streamed from the top of a computer screen, and the participants moved the mouse to get the cursor to touch the X's and avoid the O's. After each 15 s trial, participants made judgments of agency and judgments of performance. Objective control was either undistorted, or distorted by (1) Turbulence (i.e., random noise), (2) a Lag between the mouse and cursor movements (of 250 or 500 ms), or (3) 'Magic,' (i.e., an increased radius around the X's for which credit was given). In Experiment 1, college students' judgments of agency showed that they were sensitive to all three manipulations. They also indicated that they felt more in control in the Lag conditions, where there was a rule on which they could potentially capitalize, than in the matched Turbulence conditions. In Experiment 2, older adults were also sensitive to all three manipulations, but less so than the college students. They were not sensitive to the difference between the Lag and Turbulence manipulations. Finally, in Experiment 3, 8–10 year-old children were sensitive to their loss of control equally in the Lag and Turbulence conditions. However, when performance was artificially improved, in the Magic condition, children took full credit and showed no evidence that they realized that the results were due to an external variable. Together, these findings suggest that people's metacognition of agency changes in important ways across the lifespan.

1. Introduction

Until recently, the idea that people might not know that they were the agents behind their own actions was almost inconceivable. The "I" who was doing the thinking, in Descartes' (1637/1969) meditations, became his incontrovertible basis of all other knowledge. His metacognition about his own agency was the one and only thing Descartes could not doubt or deny. His thoughts could be wrong; his perceptions distorted; his knowledge inaccurate. But Descartes was unable to conceive of the possibility that it was not he who was doing the thinking and doubting. As Jeannerod and Pacherie (2004) put it: "A number of contemporary thinkers acknowledge that when I judge "I think X", I may be mistaken about X and thus that the mind is not wholly transparent of itself. But they maintain, with Descartes, that when I judge: "I think X", I cannot be mistaken about who the subject of the thought is. " (p. 114). So, too, by this view, when actions are taken, we know, unmistakably and in a uniquely privileged way, that we are doing them ourselves.

This brand of privileged access, which Ryle (l949) called the 'official doctrine', has special status in the law. Eyewitnesses accounts—the report from a witness that they saw the perpetrator—hold enormous weight, both in court, in juror's decisions, and even in the face of conflicting evidence (see, Fox & Walters, l986). However, even eyewitness reports pale by comparison to an individual's confession. There is simply no more incriminating thing that a person can do than assert that they did it. Their attribution of self-agency with respect to the act of the crime is paramount. And, although everyone acknowledges that confessions might be coerced and hence not be valid (c.f., Kassin

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& Sukel, l997), if the confession is made freely and there is every reason to suppose the confessor believes it, then we the jury take this to be the most sure evidence that exists that the person indeed committed the crime.

And yet, there are cases of uncoerced false self-confession, and that people may believe they did something they did not do (Kassin & Gudjonsson, 2004). Indeed, in laboratory situations, Kassin and Kiechel (1996) and Redlick and Goodman (2003) report that adults will confess falsely to having hit a forbidden computer key that crashed a computer, under circumstances that are far from what would be considered legally coercive. Furthermore, Redlick and Goodman (2003) found that younger children, 10–12 year olds, were more likely to confess than were older children and college students. And, when Candel, Merckelbach, Loyen, and Reyskens (2005) said to 8–10 year-old children, "You hit the SHIFT-key, didn't you?" 36% of the children—none of who had actually hit the key—said yes. There are a number of possible explanations. Perhaps the participants, and especially the younger children, were just being compliant or suggestible. But it is also possible that people have considerable uncertainty about their own actions. Perhaps the younger children were genuinely less able to discern their own agency than were the adults, and they really did not know that they had not done it. Children are also impaired, when compared to young adults, in their memory for source, as, indeed, are older adults (Schacter, Kagan, & Leichtman, 1995; Spencer & Raz, l995). These differences in source memory might be ascribable to a memory differences. But it is also possible that there are differences in online judgments of agency that vary over the lifespan. It is this possibility that we explore in this article.

That the official doctrine, itself, is not unimpeachable—at least in 'special' cases—is already known. There are many examples of abnormal attributions of agency in people with schizophrenia, or with neurological conditions such as alien hand syndrome (see, for example, Frith, Blakemore, & Wolpert, 2000; Jeannerod, 1999; Pacherie, Green, & Bayne, 2006). Drugs can alter people's metacognitions of their own agency (Kirkpatrick, Metcalfe, Greene, & Hart, 2008). And by creating clever, intentionally misleading situations, Wegner, Sparrow and Winnerman (2004, and see Wegner & Wheatley, 1999), have shown that even ordinary, healthy college students claim to have felt that they were moving someone else's hands, or that they were controlling a mouse when, in fact, they were not. Such demonstrations contradict the idea that our knowledge of our own agency is an immediate, incontrovertible given, as the official doctrine supposes.

Instead, it appears likely that our metacognition of agency is inferential, as are other metacognitive judgments (see Dunlosky & Metcalfe, 2009; Dunlosky & Nelson, 1992; Koriat & Ma'ayan, 2005). But saying that this knowledge is not a direct given, is not to say that these judgments are arbitrary. Far from it, making accurate judgments of agency is highly adaptive, and the person who fails at this task is at severe risk, as the seriousness of the above-mentioned pathologies affirm. Understanding what heuristics people use to make these essential metacognitive judgments, and whether their use varies over a lifespan, is essential if we are to understand how people gain and maintain a sense of agency, and, in what that sense consists. The issue that we address here, then, is whether there are systematic changes in people's judgments of their own agency over the lifespan, under conditions in which objective control is manipulated. Do healthy normal children, young adults and older adults process the information to agency differently – producing distinct age-specific judgment of agency profiles? Or are the patterns of people's judgments of agency constant over the lifespan?

In earlier work (Metcalfe & Greene, 2007), we have shown that college students are remarkably good at detecting when they are, objectively, in control, and when they are not. We had participants perform a computer-based task in which X's and O's streamed from the top of the computer screen, and the participant was able to move, via the computer mouse, a box on a horizontal bar on the screen. They were instructed to try to touch all of the falling X's with the box (which beeped when contacted) and avoid touching any of the O's (which booped). (See Fig. 1 for a static illustration of this task, which is also be the task used in the present experiments.)

After engaging in this task for a short period of time (20 s) they were asked to make judgments of their perfor-

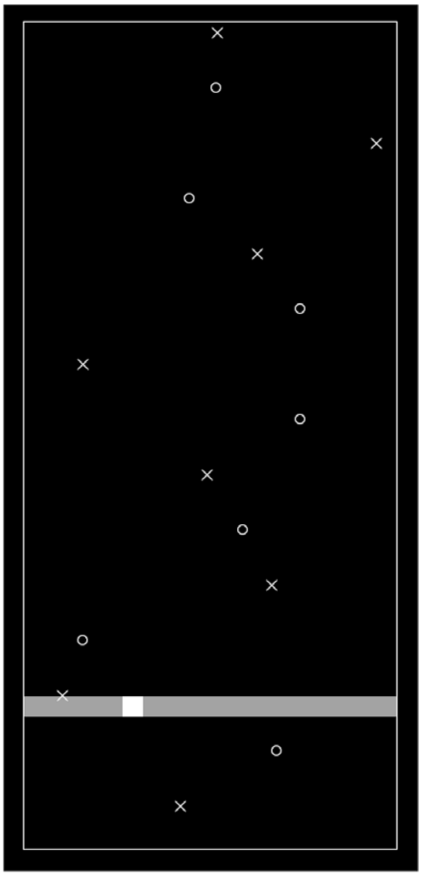

Fig. 1. A screen shot of the task. The participant moves the square on the grey bar at the bottom of the screen to 'catch' downward scrolling X's and avoid catching O's.

mance (JOPs) and judgments of their control or agency (JOAs). The findings of main interest were that the participants' judgments showed that they were sensitive to not being in control in the two conditions in which – because of the manner in which the relation between the mouse movements and the movements of the cursor onscreen on the game were programmed – they objectively did not have full control. The first such condition was Turbulence, in which random noise was added to the position of the mouse to produce the position of the cursor on the screen. This random noise objectively limited the participant's control. The second condition was 'Magic' which extended the radius that would count for a 'hit,' such that the person would be credited with touching an X even if they had not, in fact, touched it. College students' realization that they were not fully in control in these two cases was notable, because these were just the factors that they should have been sensitive to were they accurately and sensitively monitoring their own effect on the game they were playing. From these results, Metcalfe and Greene (2007) concluded that 'people' are sensitive to when they are and are not in control, and could make refined judgments of agency. Our question here is whether this sensitivity to being in or out of control, is the same for children and for older adults as it is for the college students. Metacognition, memory, and especially source memory, physical strength, interpersonal skills, dependence upon other people, cognitive skills, motor speed, and many other factors vary across the lifespan and might impact people's feelings of agency. But, at the present time, there is virtually no empirical information about differences in this domain. In addition, in the experiments that follow, we add a third condition – Lag – which will be described in more detail below.

There are several conceptual frameworks relevant to people's JOAs. We will briefly consider four of them. First, Wegner (2003) has suggested a framework in which there is an unconscious cause of action that leads to action, and an unconscious cause of thought that leads to thought. When these two co-occur within a particular time frame (i.e., when the conscious thought – that people take to be their intention – occurs before, but not too much before, the corresponding conscious action) then people think that the thought caused the action. When this happens, they will perceive themselves to be the agent, provided that the action cannot (easily) be attributed to other causes. The Wegnerian view might say that, in our game situation, the person's intentions would be to touch the X's and avoid the O's – but not much more detail is given. Insofar as there is no obvious other player to whom to attribute actions in the game, and insofar as the outcome is good (and hence consistent with one's intentions) the attribution of agency should be made to the self. One might expect, by this view, to find that people's JOPs and their JOAs are interchangeable. More fine-grained predictions are difficult to determine, however, and the framework makes no particular predictions about possible life span differences.

Second, Johnson and Raye (1981) proposed a reality-monitoring model called MEM (multiple entry memory system) in which reality monitoring and source monitoring depend, inferentially, on the information given or remembered and the expectations of the individual. More specifically, Johnson, Hashtroudi, and Lindsay (1993) stated that people make attributions about the origin of their mental experiences based on the phenomenal qualities of those experiences (e.g., amount of perceptual, contextual and emotional detail; cognitive operations information) as well as inferences, expectations, and biases introduced by prior knowledge, beliefs, and motivations. This model, too, can be applied to attributions of agency, especially in terms of how certain evidence is weighted in terms of the individual's goals, beliefs and agendas. By this view, one might expect that internal cognitive operations and emotions could impact on people's JOAs, though exactly how, is not specified. Insofar as source judgments might be related to JOAs, and certain source judgments are impaired both in children and in older adults, MEM opens up the possibility that JOAs might also be impaired in these populations. Then again, the source memory impairment might not be attributable to an impairment in the initial perception of agency, but might, instead, be a pure memory effect. If so, JOAs may be unimpaired in children and in older adults.

A third view is proposed by Frith, Blakemore, and Wolpert (1999), and see Blakemore, 2003; Haggard, 2005; Wolpert, 1997) who have forwarded a brain-based framework for motor control that can readily be applied to people's metacognitions of agency. This model was originally devised to allow fine-grained correction of motor movements, rather than as an explanation of people's JOAs. Even so, it has been shown to be useful in illuminating our understanding of the processes that might, potentially, underlie accurate agency judgments as well as such misattributions as are seen in people with schizophrenia. According to this model, when a person has an immediate goal, it gives rise to an internal model that is a kind of rough sketch of their intentions about achieving the goal, and how these intentions might be actualized. This may initiate a motor plan, called the forward model, which gives the specifications about what the muscles need to do, online, to achieve the goal. The forward model is a detailed expectation of what should happen given this plan, and it runs off in real time simultaneously with the person's actual motor actions allowing moment to moment evaluation, by a comparator, of the correspondence of the actions and the plan. If the expectation and the outcome—conveyed via the afferent and efferent pathways—are the same, the comparator registers a null result, indicating that the person's intentions are in perfect synchrony with what is happening, and indicating that they are in control. A discrepancy, however, indicates that something or someone else is interfering with the action. In schizophrenia, the internal feedback from the person's own actions may be distorted, and this may give rise to a spurious discrepancy and hence to inappropriate feelings of external control. This framework makes a very clear prediction that people who are experiencing a fine-grained discrepancy between their intentions and their monitored movements should be able to detect this and should report feeling out of control—providing a good explanation of the observed feeling of a lack of agency in the Turbulence condition in Metcalfe and Greene (2007), for example. The model, nicely, even points to a brain locale (the temporal parietal junction, with cerebellum involvement) where one might seek to find evidence of this discrepancy. However, what the model does not do is detail any predictions about what might happen as a function of age. Still, if age-related differences were observed, this model provides the promise of contributing a detailed computational basis for understanding them.

Finally, a Kantian perspective would allow that a judgment of agency is just a special kind of causality judgment where the self is the cause. Judgment of self-causality, like other causal judgments, is dependent upon the individual detecting a mediating rule between the purported cause and the effect. As Kant argued (1783/1950/1983, p. 62): "the concept of cause implies a rule according to which one state follows another necessarily." The rule, according to the Kantian perspective, does not have to be direct and immediate contact, or temporal contiguity. Indeed, it could be any rule, so long as the person is capable of picking up on it. In this sense, the Kantian perspective is compatible with the view that metacognitive judgments are cue-dependent and inferential. The heuristics, in the metacognitive view, are the rules in the Kantian perspective. It is possible, from this perspective, that not all people are able to pick up on the same rules that mediate between their own movements and their effect. To the extent that people are differentially sensitive to some or all of the mediating rules, because of factors such as experience, maturation, neuronal noise or damage, motivation, or differential motor sensitivity, say, then they will exhibit different profiles in their JOAs. The Kantian perspective, therefore, suggests the possibility of systematic age-related differences in metacognition of agency.

While we now have several conceptual frameworks within which to view people's judgments of whether they are or are not controlling an action, the empirical research lags behind. There have been only a few systematic studies, to date, on what variables affect people's JOAs or whether there are differences among normal healthy people. We focus, here, on three experimental manipulations that objectively do alter people's control, and that, therefore, should alter their JOAs: Turbulence, Magic, and temporal Lag.

Each of the three variables we investigate makes a different contribution to our understanding of people's agency, and to the meaning of the metacognition of agency profile that people of different ages exhibit. The Turbulence factor hurts performance due to external interference coming between the person's intent and the outcome. It should be relatively easy to detect, both because the intervention between intent and outcome is obvious and because the outcome is unfavorable. So, a model like the forward model in which intent is characterized in a detailed real time motor plan would detect the discrepancy. But even if intent were characterized more globally as simply wanting to do well, it is possible that the person would detect that they were not doing so well as they thought they should in the Turbulence condition. Magic, in contrast, intervenes between the person's detailed intent and what transpires, but in a favorable way. Thus, Magic should be detected if agency judgments are based on detailed monitoring of a discrepancy between one's plans and their outcome, such as in the forward model. However, if the intent were only coded more globally as wanting to do well, then, with Magic – a condition in which participants do extremely well – no violation of agency should be detected. The Magic condition, thus, allows discrimination between the use of global intentions or goals versus detailed online plans and expectations, in assessment of agency. Finally, Lag, a condition in which the movement of the cursor onscreen exactly mirrors the movement of the mouse, but at a delay, is an interesting variable because while it is an intervention that comes between the person's intention and the outcome both in detail and globally, and which hurts performance, the nature of that intervention is lawful. There is a 'rule' – in the Kantian sense – between the intent and the outcome. However, this rule may be difficult to perceive. Accordingly, Lag may be a manipulation that is detected as different from Turbulence only by those most highly attuned to the nuances of their own effect on the game. It may go unnoticed by others. We will look for systematic differences in the profile of responses to these three manipulations across the lifespan, studying, first, college students (in Experiment 1), then older adults (in Experiment 2) and finally children (in Experiment 3). No previous lifespan studies on metacognition of agency have been conducted, and, thus, the research reported here provides an initial exploration into how various feelings of agency may develop in normal healthy people over the lifespan.

2. Experiment 1

Because, from our own past experiments, we already knew that college-aged students correctly realize that they are not fully in control in the Magic and Turbulence conditions (that we will use in all three experiments), we were most interested in Lag, a new experimental manipulation that we introduce here for the first time. If JOAs are similar to other judgments about causality, except that the question is not "Did A cause B" but rather "Did I, myself, cause B," then temporal Lag should have a systematic effect. The Lag that we interposed in the experiments that follow was simple: when the person moved the mouse, the cursor on the screen followed, but either 1/4 s, or 1/2 s after the mouse had moved. To what extent should the person think they were controlling the movement of the cursor, under these conditions?

From the empirical research on people's perception of causality it seemed likely that Lag would be an important variable. For example, Michotte (l963) has argued, and many experiments have demonstrated (e.g., Hubbard, Blessum, & Ruppel, 2001), that when people see a moving object move into contact with another object which is initially stable, and then when the second object begins to move immediately – continuing the movement of the first object – they perceive the first object as causing the movement of the second. Michotte argued that this perception that the movement of A caused B to move is innate, direct and hardwired, and called this direct perception of causality the 'launching' effect. Saxe and Carey (2006) reviewed the literature, and showed that, even in infants, launching events are perceived causally. The launching effect seems most relevant to the Control condition in our experiments, in which the cursor movement maps directly, with no time delay, onto the movement of the mouse, which then has consequences for hits and misses in the computer task.

A number of experiments have also investigated people's judgments of causality when a temporal Lag is inserted between the impact of object A with object B and the movement of object B. For example, Schlottman and Shanks (l992) investigated people's ratings of causality on a scale from 0 to 300 when the delay between when A touched B, and when movement of B began was delayed by 17, 85, 153, 221, or 289 ms. The decrease in causality ratings as the delay increased was both systematic and large, with ratings for the 17 ms delay hovering higher than 200, while those for the 289 ms delay being only around 75. The intermediate delays were intermediate and well behaved. Notably, even at the largest delay tested, though, their participants still did not judge the sequence as being completely not causal: the value of about 75 was still well above zero, consistent with the Kantian idea that people could still pick up on something about the rule that mediated between A and B. It is also notable that people are also able to learn to navigate under temporal delays (Cunningham, Billock, & Tsou, 2000).

Thus, although we would expect that with a time delay in the responsiveness of the cursor to the mouse, there would be a decrement in people's JOAs as compared to the control condition in which there was no time delay, we also hypothesized that people might not have as much of a decrement in their JOAs with time delay as would be apparent in a matched comparison condition where there was no rule or correlation relating the movement to the outcome. This prediction was made on the assumption that participants would be able to pick up on the temporal Lag rule. As with a slow brake in a car, or a steering wheel that turns where you turn, but with a time delay, people might realize that there was a mediating rule, and exhibit less of a feeling of loss of control than when no discernible rule existed. If they were not able to pick up the rule, though, then the Lag condition should result in agency judgments equivalent to those in a matched Turbulence condition. Given Schlottman and Shanks (l992) data showing a decrease in perceived causality with increased time Lag, we also expected that people would feel less out of control in the 250 ms Lag condition than in the 500 ms Lag condition.

To be able to determine whether Lag was having the same or a different effect than Turbulence, though, we needed to match the two conditions for the Amount of Discrepancy in each. Accordingly, we constructed the computer program to equate the Lag and Turbulence conditions in terms of the overall variability in the difference in the position of the mouse with respect to the position of the cursor, at each point in time, as will be described in the methods section, below. Our hypothesis was that people's JOAs, relative to the Control condition, would be lower in the Turbulence conditions than in the matched Lag conditions, because we hypothesized that people would be able to pick up on the rule (that their movements were correlated in a systematic way with the outcome) that mediated in the Lag condition. Given that there was no rule in the Turbulence condition, there was nothing to pick up on. We also predicted that their JOAs would be lower than their JOPs in the Magic condition, as had been previously shown.

2.1. Method

2.1.1. Participants

The participants were 43 Columbia University and Barnard College students (19 M, 24 F between the ages of 18 and 24) who either volunteered without pay, or who received either course credit or pay for participating. Participants were treated in accordance with the APA regulations.

2.1.2. Apparatus

All experiments were conducted on individual iMac computers, used with a mouse, and mouse pad. Participants were run individually.

2.1.3. Procedure

The instructions given to participants were: "Throughout this experiment you are going to play a game in which you will use the computer mouse to move a box on a grey track. Your job is to touch all of the X's as they come into range and to avoid touching any of the O's. After each trial, you will be asked to assess your performance. If you felt you got all of the X's, and avoided all of the O's, you should click to the far right of the blue bar, indicating everything correct. If you felt you got none of the X's, and touched all of the O's, then you should click to the far left, indicating nothing correct. You may also click anywhere in between. You will also be asked to assess how in control you felt. If you felt you were in complete control, click to the far right of the red bar. If you felt that you had no control, click to the far left. You may also click anywhere in between."

Participants practiced both playing the game and making judgments. During the practice trial at playing the game, which lasted for 15 s, as did all subsequent trials, the X's or O's disappeared as soon as the person touched them, but continued on screen below the mouse track, if the person did not touch them. Additionally, a distinctive beep sound accompanied hits and a boop sound accompanied false alarms. After each 15 s trial, the participant made a JOA, that is, of how in control he or she felt, and then a JOP. These judgments were made by moving the mouse along a dull colored bar to pull a more brightly colored indicator to the desired point along a clearly marked visual analogue scale. The scale was continuous and the participants could pull the slider to any point along it. This slider bar for the performance judgments was blue. The slider bar for the agency judgments was red. The far left of the bar was coded in our data as 0.0; the far right was coded as 1.0, with values in between being assigned their appropriate value on a linear scale. The experimenter, in this and all other experiments, made sure that the participant understood how the scale worked and what the difference between these two types of judgments were by having the participant report what each judgment meant, during the practice trial. After the practice trial, the experimenter asked if there were any questions, and if there were, he or she answered them. The participant was permitted to practice as many times as they wanted before starting the experiment proper. Once they affirmed that they were ready to begin, they hit the continue button, and went through 24 trials of game play followed by judgments after each trial. At the end of the experiment, the participant was questioned about what they had done, was debriefed, given credit or pay, and was thanked.

2.1.4. Design

The experiment included six within participants conditions: a Control condition in which the participant had perfect control of the mouse, a small Lag condition (Lag 1) in which the cursor responsiveness lagged the mouse position by 250 ms, a large Lag (Lag 2) condition in which the cursor position lagged the mouse position by 500 ms, a small Turbulence (Turbulence 1) condition, which was noise-matched (as will be described shortly) to the Lag 1 condition, but in which the discrepancy was random rather than Lagged, a large Turbulence (Turbulence 2) condition, which was discrepancymatched to the Lag 2 condition, and, finally a Magic condition. There were four replications of the six conditions, in a quasi-random blocked order, across the 24 trial sessions. As will be described below, the amount of noise in the Turbulence trials was matched to the Amount of Discrepancy between the mouse position and the cursor position, every 8 ms, in the Lag condition. To determine this discrepancy, the Lag conditions had to come first, which constrained the randomization of the order of conditions within block, though all conditions were well distributed over the entire session. The data from the four trials in each of the six conditions were collapsed. The Control condition was included as a baseline for the other conditions.

The Lag and Turbulence conditions, with high and low levels of noise, comprised a 2×2 design that was nested within the experiment, with factors that we will call Type of Discrepancy (Lag or Turbulence) and Amount of Discrepancy (1: low, or 2: high). Since these two conditions were equated with one another, they will be analyzed as a proper 2×2 design to allow investigation of people's sensitivity to the kind of discrepancy – whether it was correlated "noise" from which a rule could, potentially, be extracted, or completely random noise from which no rule could be extracted.

There were two dependent variables of central interest. The first was people's JOP: How well did they think they did on touching the X's and avoiding the O's? This was measured on the analogue slider scale coded from 0 to 1.0. The second dependent variable was JOA: How in control, on an analogue scale coded from 0 to 1.0, did they think they were? We also computed actual performance using hit rate and false alarm (reported as proportions), and using d'. The number of possible hits and false alarms varied slightly over trials, depending upon where exactly the first random placement of X's and O's occurred. The mean total number of X's that could be touched in the 15 s trial interval was 13.94 (SD = 2.57), and the mean number of O's was the same. The amount of mouse motion on each trial was also recorded.

2.1.5. Program

The layout of the game on the screen is shown in Fig. 1, and was already described. Constructing the Lag condition entailed plotting the cursor position on the screen to be the position that the mouse had occupied 250 ms earlier. Thus, there was a one-to-one correspondence between the mouse position and the cursor position that was bridged by a 250 ms (in the Lag 1) or a 500 ms (in the Lag 2) time delay. We recorded the position of the mouse and the position of the onscreen cursor at every tick of the computer clock, that is, every 8 ms. The discrepancy between the actual mouse position at every tick of the computer clock as compared to the cursor position at the same moment determined a (signed) discrepancy distribution. Over the entire 15 s trial, a series of discrepancies between the cursor and Lag position at each point in time were thus measured, and this set was then randomized, and the signed difference was used to determine what the 'noise' would be in the Turbulence condition. The discrepancies found in the Lag condition were randomized – so that they no longer correlated in any way with the cursor position or with the time in the trial, but so that their magnitude and direction were maintained – and these discrepancies were added, at 8 ms intervals, to the position of the mouse in the Turbulence condition, to result in the position of the cursor, on screen. The discrepancies were smoothed to decrease the jerkiness that resulted. The Turbulence was hence random, but it was discrepancy-matched or noise-matched to its corresponding Lag condition, on a trial-by-trial basis (except for the first 1/4 or 1/2 s interval in each trial, during which we could not apply this algorithm). If one were to compute the sum of squares of the discrepancy between mouse and cursor position in the Lag and Turbulence conditions, they would be identical. The positions of the mouse and the cursor were recorded, online, for every trial in the experiment, every 8 ms, and so we were able to crosscheck this. We did this and the mean squared errors – giving the discrepancy between the mouse position and the cursor position in the Turbulence and matched Lag conditions – were identical (aside from the few ticks at the beginning of each trial, which were undistorted). Because of this matching algorithm, the Amount of Discrepancy – where discrepancy is considered to be the difference between the mouse position and the cursor position at each clock tick over the entire 15 s trial – was identical in the Lag condition and in the matched Turbulence condition, and so Type of Discrepancy could be treated as a factor. The difference between these two conditions was only that the discrepancy in the Turbulence condition was random, while the discrepancy in the Lag condition was perfectly and lawfully mediated by a time Lag rule.

In the Control condition, there was no discrepancy between the cursor position and the mouse position. In the Magic condition, the X's disappeared and the beep for a hit occurred as long as the mouse position was within a 15 pixel range of the target, which was about ½ in. on the screen, rather than having to be exactly on the target (as was necessary in all other conditions).

2.2. Results

2.2.1. Performance

We computed people's hit rates, false alarm rates, and d' values. All three analyses showed the same thing. Performance varied with the conditions in the experiment, in the expected way, as is shown in Table 1. Best performance was seen in the Magic condition. The Control condition exhibited moderate performance, and both Discrepancy levels in both the Lag and Turbulence conditions showed poor performance. An ANOVA showed the main effect of Conditions to be significant, as expected, for hit rate ($F(5, 252) = 514.99$, $p < .001$, $MSe = 3.47$, $\eta_p^2 = .91$) (effect size is reported using partial eta squared, η_p^2), for false alarm rate ($F(5, 252) = 81.74$, $p < .001$, $MSe = .18$, $\eta_p^2 = .62$) and for d' ($F(5, 252) = 466.81$, $p < .001$, $MSe = 87.72$, $\eta_p^2 = .90$).

The mean total movement, in pixels, was 3.84×10^4 (s.d. = 2.54×10^4).

2.2.2. Judgments of performance

People's JOPs followed their performance curves. JOPs were highest for the Magic condition, next highest for the Control condition, and lower for both the Turbulence and Lag conditions as is shown in Table 1. An ANOVA showed that the main effect of Conditions was significant ($F(5, 252) = 137.59$, $p < .001$, $MSe = 33168.92$, $\eta_p^2 = .73$). We also looked at the calibration of JOPs to the proportion of hits. Fig. 2, panel A, shows the college students' hit rate in comparison to their JOPs for the six conditions. As can be seen, participants' JOPs closely followed their performance, and they were underconfident in all conditions.

2.2.3. Relation of judgments of performance to performance: metacognitive accuracy

The Pearson correlations, for each participant, were computed between their JOPs and their hit rate on each trial, to give some idea of their relative accuracy. These correlations were well above zero in all cases, with no participant scoring below zero. The mean correlation, over all participants was $r = .89$, which was different from zero ($t(42) = 78.23$, $p < .001$), and which showed that metacognitive accuracy about how well they had done was very good.

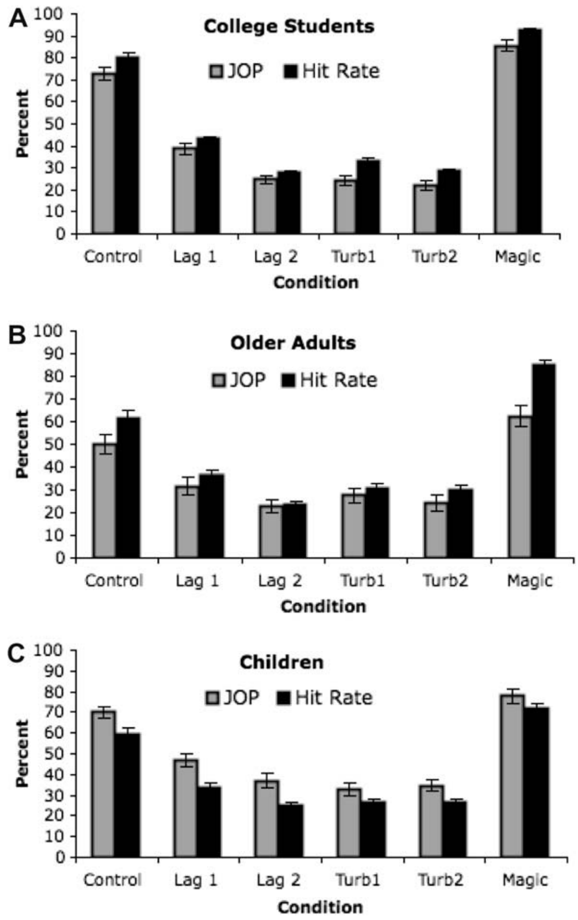

Fig. 2. Metacognitive calibration across conditions: judgments of performance as compared to and hit rates are given for college students, in panel A, for older adults, in panel B, and for children, in panel C.

Table 1
A summary of performance measured by hit rate, false alarm rate, d', JOP, and JOA, in college students, older adults, and children.

		Control	Lag 1	Lag 2	Turb 1	Turb 2	Magic
Hit rate	College students	.81 (.10)	.43 (.09)	.23 (.07)	.33 (.09)	.29 (.08)	.93 (.05)
	Older adults	.62 (.18)	.37 (.10)	.23 (.08)	.31 (.07)	.30 (.08)	.85 (.10)
	Children	.59 (.17)	.34 (.12)	.25 (.08)	.27 (.08)	.26 (.08)	.72 (.15)
False alarm rate	College students	.05 (.03)	.14 (.06)	.14 (.06)	.19 (.05)	.18 (.05)	.03 (.03)
	Older adults	.11 (.06)	.16 (.08)	.19 (.07)	.19 (.05)	.21 (07)	.12 (.08)
	Children	.07 (.03)	.12 (.05)	.13 (.03)	.17 (.05)	.16 (.06)	.07 (.03)
d'	College students	2.92 (.56)	1.04 (.42)	.57 (.42)	.49 (.38)	.44 (.39)	3.73 (.47)
	Older adults	1.78 (.73)	.75 (.50)	.17 (.41)	.43 (.39)	.33 (.44)	2.55 (.72)
	Children	1.89 (.61)	.84 (.45)	.49 (.37)	.36 (.33)	.43 (.40)	2.32 (.66)
JOP	College students	73.09 (13.53)	38.71 (16.54)	24.67 (14.99)	24.37 (13.54)	21.79 (14.38)	85.64 (10.28)
	Older adults	49.96 (12.99)	31.55 (11.44)	22.90 (8.97)	27.68 (10.86)	24.27 (8.23)	62.32 (10.64)
	Children	69.93 (18.85)	46.69 (20.99)	36.96 (20.51)	32.63 (19.14)	34.73 (19.81)	77.74 (14.92)
JOA	College students	79.53 (23.52)	35.08 (22.76)	23.42 (20.49)	17.53 (18.69)	14.21 (16.76)	84.37 (20.83)
	Older adults	49.30 (25.81)	28.63 (20.15)	19.70 (15.33)	24.11 (18.22)	20.51 (16.55)	59.51 (25.09)
	Children	71.17 (29.58)	42.19 (30.54)	30.63 (29.23)	27.99 (27.97)	28.53 (28.95)	78.37 (25.24)

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2.2.4. Judgments of agency

Previous research had shown a strong correlation between people's JOPs and their JOAs (see Table 1). This correlation was also found in the present experiment, when we computed the correlation between these two dependent variables across the 24 trials. The mean Pearson correlation was $r = 0.87$. A Fisher's transformation on the correlations was performed, and the transformed values were significantly greater than zero, $t(42) = 17.99$, $p < .001$.

Metcalfe and Greene (2007) noted that people's JOAs, as distinct from their performance, should be assessed relative to their own *perception* of their performance, rather than relative to their actual performance, since it is not how they are doing objectively that counts, but how they think they are doing. The use of JOP, to anchor JOA, also provides some leverage on how individual's used the rating scale. The scale, itself, was the same for the two judgments. The question of interest, in evaluating the accuracy of people's JOAs is whether they picked up – in the conditions in which they are not fully in control – on their lack of control, over and above their perception of their overt performance. Thus, to evaluate people's metacognition of agency we compared their JOAs to their JOPs. Because there may be scaling effects in how they ground the judgment of agency scale we here used the Control condition – in which there were no distortions of their actual control – to anchor their use of the performance and the agency scales. Thus, in the analyses that follow we use the difference between JOPs and JOAs in the Control condition as the baseline against which we evaluate differences in these two judgments that occur in the experimental conditions of interest, namely Turbulence 1, Turbulence 2, Lag 1, Lag 2 and Magic.

To evaluate whether people experience a greater decrement in their feelings of agency in the conditions in which they actually do not have full control, then is apparent from simply their perception of their performance, we computed summary 'agency' scores for the two Turbulence conditions, the two Lag conditions, and the Magic conditions. In each of these five cases we computed $(JOP_C–JOA_C)–(JOP_E–JOA_E)$ where the subscript C refers to the control condition and E refers to the particular experimental condition of interest (which could be Turbulence 1, Turbulence 2, Lag 1, Lag 2, or Magic). This summary score should be negative, so long as people realized that their performance, in the experimental condition being considered, was not entirely due to their own control. This holds for conditions in which performance is harmed or helped by the external manipulation of control. A zero means that they thought they were in control. (This summary score compresses the interactions between JOP and JOA in previous research into a single measure.) Because Lag and Turbulence were equated, as given in the methods section, and because the difference between these two factors was of primary interest, we treated the four conditions involving Lag and Turbulence as a fully crossed 2×2 design, where the factors were Type of Discrepancy (Lag or Turbulence) and Amount of Discrepancy (1 or 2). We evaluated Magic separately.

As is shown in Fig. 3, the Type of Discrepancy had an effect on college student's assessment of their own agency in this experiment. They felt more in control in the Lag conditions ($\overline{X} = -8.89$), than in the matched Turbulence conditions ($\overline{X} = -13.66$, $F(1, 42) = 9.37$, $p = .004$, $MSe = 104.16$, $\eta_p^2 = .182$). There was no effect of Amount of Discrepancy ($F < 1$), and the interaction between Amount of Discrepancy and Type of Discrepancy was not significant ($F(1, 42) = 2.09$, $p = .16$, $MSe = 50.01$, $\eta_p^2 = .05$). Thus, college students felt more in control in the Lag than Turbulence conditions, suggesting they were sensitive to the rule-based correlation in the Lag conditions.

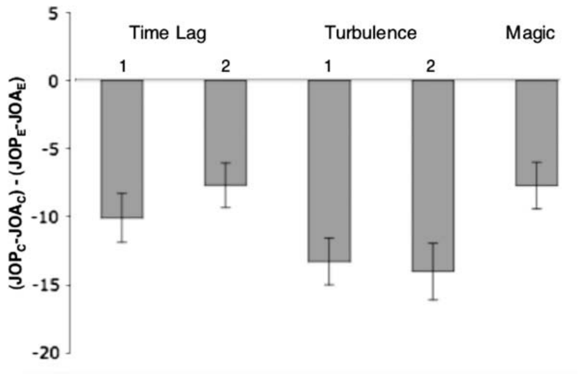

Fig. 3. College students' agency scores given by $(JOP_C–JOA_C)–(JOP_E–JOA_E)$, where C refers to the control condition, and E refers to the experimental condition, respectively: Lag 1, Lag 2, Turbulence 1, Turbulence 2, or Magic. A negative score indicates that there was a correct perception of not being in control.

Because there was no difference as a function of Amount of Discrepancy, we collapsed over this variable, and conducted *t*-tests against zero, to determine whether college students rated themselves as not in control, under conditions in which they were objectively not, completely, in control. The summary agency scores in both the Turbulence condition ($\overline{X} = -13.65$, $t(42) = 7.95$, $p < .001$) and the Lag condition ($\overline{X} = -8.89$, $t(42) = 5.66$, $p < .001$) were significantly less than zero indicating that in both conditions people knew that they were not completely in control. Finally, we also computed summary agency scores for the Magic condition. These, too, were significantly negative ($\overline{X} = -7.71$, $t(42) = 4.5$, $p < .001$), indicating that in the Magic condition – in which performance increased as a result of the manipulation – the college student participants in this first experiment recognized that they were not fully in control.

2.3. Discussion

The results of this experiment, on the Turbulence and Magic factors, replicate the earlier results of Metcalfe and Greene (2007): college students judged that they did not have full control (relative to their judgments of performance) under conditions where they, in fact, did not have control. All of the other results concerning JOP, and actual levels of performance, are also consistent with the earlier results. In particular, their basic metacognitions, as measured by the correspondence between their judgments of performance and their actual performance, were extremely good, in this task. They performed well, and they knew

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they performed well – but more importantly, for our purposes, they were highly sensitive, even when performance was extremely good, to when this was attributable to themselves and when it was not. This was also true when performance was hurt by the extraneous factor of random noise or Turbulence: people knew that they were not completely in control.

The most interesting new finding in the present study, though, related to the Lag variable we introduced into this experiment. Although the amount of distortion of the mouse position from the cursor position was the same in the Lag 1 condition and the Turbulence 1 condition, and in the Lag 2 condition and the Turbulence 2 condition, the participants' JOAs in the matched Lag and Turbulence conditions were different. They judged their agency to be higher in the Lag conditions, where there was a rule that mediated the divergence, than in the Turbulence conditions, where there was no such rule. This sensitivity to this subtle rule – in terms of their feelings of being in control – was extremely interesting. In the experiments that followed, we sought to determine whether other populations of participants would also pick up on this rule as well. Indeed, since neither healthy older adults nor school aged children – the participants in the next two experiments – had ever been tested even in the other conditions of the experiment, we sought to determine not only whether they would pick up on the temporal Lag variable as being distinct from the Turbulence variable, but also whether those other population were even sensitive to Turbulence and Magic.

3. Experiment 2: older adults

In the second experiment, we investigated metacognitions of agency, as well as the other metacognitive JOP in normal, healthy, high functioning older adults. Since this is the first study looking at older adults' metacognitions of agency, we have no extensive literature to review. In the context of monitoring memory performance we do know (Hertzog, 2004; Hertzog, Kidder, Powell-Moman, & Dunlosky, 2002) that normal older adults rarely show any deficits in this type of metacognition, although some work suggests that older adults are sometimes overconfident, given their poorer overall memory (see, Conner, Dunlosky, & Hertzog, 1997). When taking into account overall poorer memory performance, Hertzog and Hultsch (2000) have shown that older adults' feelings of knowing correlations between what they think they will be able to remember and what they later can remember are just as good as those of college students. From these results, we had no reason to suppose that there would be a deficit of any sort in the particular metacognitions we were investigating – either the metacognitions of performance, or the metacognitions of agency. But although there were data on the former, there were none on the latter kind of judgment.

Impairments have been found in the source memory of older adults, however (Henkel, Johnson & Leonardis, 1998; Spencer & Raz, 1995). Only a few studies have evaluated source memory for self versus others, and the results are mixed. For example, while Hashtroudi, Johnson and Chrosniak (1989) found that older adults had no more difficulty than young adults in distinguishing memories from different classes (externally given from internally generated). Hashtroudi, Johnson, Vnek, and Ferguson (1994) found that older adults did have more difficulty than young adults in discriminating what they had said from what others had said, when they were describing a short play and discussion in which they had participated. Thus, the data are not very clear on whether there is a deficit in self-other source memory. It is also not clear – assuming that there is a suggestion of a deficit – because there could be an impairment in the initial online monitoring of source, or (as seems more likely) it could be that source memory entails fine-grained memory, and older adults tend to be impaired on many memory tasks, particularly on difficult memory tasks (Craik & Salthouse, 2008; Kausler, 1994). Other evidence of impairments in monitoring self-production comes from inadvertent plagiarism, and there is evidence that older adults are highly susceptible to both self- and other-forms of plagiarism (McCabe, Smith, & Parks, 2007), which may be suggestive of impairments in monitoring source information related to the self.

Source memory tasks are indisputably one of the most difficult memory tasks, and are sensitive to even slight memory impairments that do not show up in other tasks such as recognition or even recall. Thus, there is the possibility that part of the source memory impairment might be attributable to an initial deficit in agency monitoring, but this line of reasoning is highly speculative, and again, there are no direct data on the issue. Thus, it was of interest to determine how older adults might attribute performance when monitoring agency in the present task, and to determine if any deficiencies were present, which would shed light on the mechanisms that underlie metacognition of agency.

3.1. Method

3.1.1. Participants

The participants were 23 healthy older adults who were recruited from the community and were tested individually. The mean age was 78.47 years, and they reported to be in good health ($\overline{X} = 8.45$), on a rating scale of 1–10, with 10 being extremely healthy, and reported 15.27 years of education. None of the older adults reported to be using any medication that would influence their performance. The older adults in this sample had, at the very least, some experience interacting with a computer, as many report using the internet, word processors and email. In addition, the older adults in the present sample have, typically, participated in several other experiments that involve using a computer. While individual measures of computer use and familiarity with using a mouse were not obtained in the present study, there is some good reason to think that this very healthy sample had a certain degree of familiarity with computers and controlling input devices, such as a mouse.

3.1.2. Procedure

We conducted the identical experiment that had been conducted with college students with the older adults.

There were three small differences in procedure. First, the research assistant sat in the room throughout the experiment, and carefully answered any questions that the older adults might have had. Second, the older adults often engaged in one or more extra practice trials before starting the experiment, to ensure they understood the task and had practice with the mouse. And finally, at the end of the experiment, they were asked to explain how they had interpreted the instructions to make a JOA. They all answered correctly, indicating that there were no comprehension issues about what they were being asked. Other than these small procedural changes, the methods were identical – and, in particular, the computer program was identical to that used in Experiment 1.

3.2. Results

3.2.1. Performance

Performance on the task was quite good, as is shown in Table 1. As was the case with the college students, best performance was seen in the Magic condition. The Control condition exhibited moderate performance, and both the small and large Discrepancy conditions where the discrepancy was Lag or Turbulence showed poor performance. There was a main effect of Conditions for hit rate ($F(5, 32) = 111.00$, $p < .001$, $MSe = 1.29$, $\eta_p^2 = .81$), false alarm rate ($F(5, 132) = 7.59$, $p < .001$, $MSe = .04$, $\eta_p^2 = .22$), and for d' ($F(5, 132) = 68.62$, $p < .001$, $MSe = 20.72$, $\eta_p^2 = .72$), as expected.

The mean total movement for older adults was about twice as great as for the college student, 6.60×10^4 pixels, s.d. = 6.63×10^4.

3.2.2. Judgments of performance

The older adults' JOPs followed their performance curves. JOPs were highest for the Magic condition, next highest for the Control condition, and lower for both the Turbulence and Lag conditions (Table 1). A Univariate ANOVA showed that the main effect of conditions was significant, $F(5, 132) = 17.71$, $p < .001$, $MSe = 5909.38$, $\eta_p^2 = .40$. As is shown in the Panel B of Fig. 2, older adults, like younger adults, exhibited JOPs that were underconfident with respect to their hit rate.

3.2.3. Relation of judgments of performance to performance

The correlations, for each participant, were computed between their JOPs and their hit rate. These correlations were well above zero in all cases, with no participant scoring below zero. The mean correlation, over all participants was $r = .81$, which was different from zero, ($t(22) = 32.43$, $p < .001$). We contrasted the older adults to the college students ($r = .89$) on this and there was a small but significant difference, $t(64) = 3.46$, $p = .001$.

3.2.4. Judgments of agency

The mean Pearson correlation between the older adults JOP and their JOA was $r = .87$. After a Fisher's transformation of the JOA to JOP correlations, a t-test against zero was performed. This was significantly greater than zero, $t(22) = 11.58$, $p = .000$. A comparison of the transformed correlations between older adults and college students did not reveal a significant difference, $t(64) = -.55$, *ns*.

To investigate whether the older adults were sensitive to the difference between Lag and Turbulence, we conducted a 2×2 ANOVA, which showed no effect of Type of Discrepancy ($F < 1$), no effect of Amount of Discrepancy, ($F < 1$) and no interaction between Type of Discrepancy and Amount of Discrepancy ($F < 1$). Thus, the older adults were *not* sensitive to the Lag manipulation the way that the college students had been.

The older adults, however, *were* appropriately sensitive to their loss of control in both the Lag and Turbulence conditions. Because Amount of Discrepancy was not significant, we collapsed over this variable, as before. The Turbulence score was significantly lower than zero ($\overline{X} = -3.02$; $t(22) = 2.52$, $p = .02$), as was the Lag score ($\overline{X} = -2.41$; $t(22) = 2.45$, $p = .02$). Finally, we also computed a summary score for the Magic condition. This, too, approached being significantly negative ($\overline{X} = -2.16$, $Mse = 1.19$, $t(22) = 1.82$, $p = .04$, one-tailed), indicating that in the Magic condition, in which performance increased as a result of the manipulation, the older adults recognized that they were not fully in control, and they rated their agency lower than their performance judgments. Fig. 4 illustrate these results.

3.2.5. Additional analyses

Since the task that the older adults and the college students performed was the same, we were able to compare the two groups directly on their metacognition of agency. We conducted a 2 (Group, college student or older adult – between participants) $\times$ 2 (Type of Discrepancy, Turbulence or Lag – within participants) $\times$ 2 (Amount of Discrepancy, small or large – within participants) ANOVA on the agency summary scores. There was a main effect of Group ($F(1, 64) = 16.36$, $p < .001$, $MSe = 268.16$, $\eta_p^2 = .20$) indicating that the older adults were less sensitive to the loss of control than were the college students. The main effect of Type of Discrepancy was significant ($F(1, 64) = 5.74$, $p = .02$, $MSe = 75.28$, $\eta_p^2 = .08$), but it was primarily due to

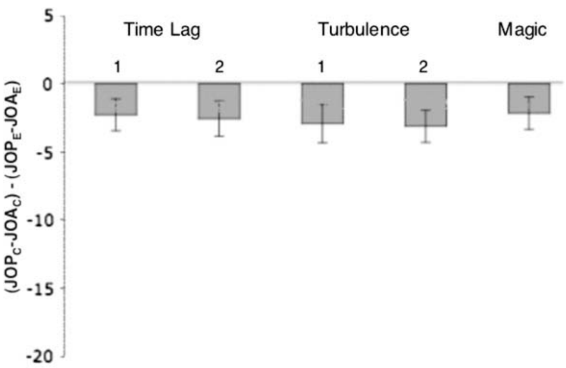

Fig. 4. Older adult's agency scores given by (JOP_C–JOA_C)–(JOP_E–JOA_E), where C refers to the control condition, and E refers to the experimental condition, respectively: Lag 1, Lag 2, Turbulence 1, Turbulence 2, or Magic. A negative score indicates that there was a correct perception of not being in control.

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the college students. The interaction between Group and Type of Discrepancy approached significance ($F(1, 64) = 3.45$, $p = .07$, $MSe = 259.48$, $\eta_p^2 = .05$). A t-test on the Magic summary scores alone also revealed a significant difference between the two groups ($t(64) = 2.22$, $p = .03$), indicating that the older adults were less sensitive to the loss of control than were the college students.

3.3. Discussion

The older adults exhibited excellent metacognitions about their performance on this task, and the sensitivity of their JOA was good, but not quite as good as that of the college students. They knew that they were not in control when the mouse control was distorted by Turbulence and by a Lag. They also knew that they were not in control when they got the X's by Magic. Thus, although there could be many factors, including, for example, a decrement in their actual motor control, and less experience with computers than the students, which might mitigate against sensitivity to their own control in this situation, the older adults were good at the task, both in terms of their performance and in terms of their monitoring of their own control. The one variable to which they were insensitive was the Lag variable, as being different from the Turbulence variable. The rule that mediates the Lag condition appears to be quite subtle, and it may be for that reason that the older adults did not pick up on it, as had the college students.

4. Experiment 3: children

In the final experiment in this series, we investigated the metacognitions of agency in normal grade 3–5 children. As with the older adults, there are no data on grade school children's metacognitions of agency. However, there are some hints with much younger children that might, tentatively, suggest that there could be some impairments on these judgments. Several oddities in the beliefs about their own agency have been found in very young children, such that they sometimes attribute actions to themselves that they could not possibly have enacted, but usually by age 5 no peculiarities have been seen. One reason for not testing children much younger than 8 years old (grade 3) in our paradigm is that we considered it essential that the children understand what the question was that they were being asked, and we also wanted them to be able to handle the computer and the ratings scales with some facility. Although we did not collect data on the children tested on computer usage, we did conduct a short survey on grade 3 and 5 children, in the cohort following this group, and found that computer usage ranged from 0 h per week (aside from being in our studies, for about 1 h per week) to a maximum of 20 h per week for selected individual children. Most of the children used computers 2–4 h a week. The children were familiar with google, e-mail, and often games. The children we tested all, also, had experience with using the slider scales for making metacognitive ratings, because they had used sliders in other experiments in our lab. We tested the children individually, with an adult research assistant in the room at all times, to make sure that they understood what they were being asked.

Although we know virtually nothing about school-aged children's metacognition of agency, results with very young children suggest that they may not have a perfect understanding or perception of their own control of an action. For example, Schultz, Wells and Sarda (1980) used a reflex hammer to induce a knee-jerk reflex in children 3 and 5 years old. When the children were asked whether they had meant to move their legs, the three years olds said they had meant to move their legs, while the 5 year olds said they had not. These results suggest that a gross attribution of control might not yet be in place by age 3. Pacherie (2007) argued that if the child sensed a feeling of control over the movement they should say yes, and otherwise no, in this task. But, she says, such a difference in the feeling of agency cannot account for the differences observed by Schultz et al. (1980) because "presumably both groups of children enjoy the same phenomenology" (p. 22). She suggested that the reason for the difference between the younger and older children may have been that they had differences in their top-down beliefs about the differences between reflex movements and other movements such that the older children have beliefs that reflex movements are movements that they cannot control whereas the younger children do not have these beliefs. Alternatively, or additionally, she suggested that young children may not have developed a sufficient mastery of the concepts of intention or intentional action, and this failure to have mastered the concept may have influenced the results.

Interestingly, Lang and Perner (2002) found that the appropriate denial of agency, in the case of the reflex response, correlated strongly with correct performance on the false belief task, and also with executive function tasks. They argued that appropriate agency attribution might accompany the development of other metarepresentational abilities. However, these abilities are thought to be firmly in place by the age of the children we tested.

There are also differences in source judgments between children and adults and younger children and older children (Lindsay, Johnson, & Kwon, 1991). But these may not apply to discrimination between self and other – the judgments most related to metacognition of agency. Foley, Johnson and Raye (1983) found that younger children (age 6) were less able than older children to discriminate themselves thinking versus saying something. But they were equally able to remember whether they themselves said something as contrasted with another person. So, we cannot tell from past data just what to expect.

In the unlikely case that the children were simply unable to differentiate internal from external causation, we expected that they would be random on their judgments of agency. We thought this highly implausible, but possible. Given that children at this age exhibit very good metacognitions about what they know and do not know (Schneider & Lockl, 2002), we also expected that they would, here, exhibit very good assessments of their own performance.

An alternative possibility for how children might spuriously assign JOA stems from the observation that very young children – again, younger than those we tested here – sometimes apparently confuse their desires with their intentions. A number of researchers have noted that younger children may not yet understand the distinction between desire and intention and that they will tend to say that an action was intended if its outcome satisfies a desire they have. Astington (2001) for example, showed that younger children will tend to say that accidental action was intended if its outcome satisfies a desire they have. To the extent that the goal of our task to do well on the computer game—touching many X's and few O's—was the desire of the children, then, if the children were operating on some kind of interchangeability between desire fulfillment and agency, we thought that their agency judgments would simply track their performance judgments: they would say they were in control to the extent that they perceived themselves to do well, and to be out of control to the extent that they perceived themselves to do badly.

A third possibility existed, and that is that the children were old enough by grade 3–5 to have excellent and finely honed JOAs. There was a possibility that their data would look very much like that of the college students. We had no reason to favor any of these three possibilities, since there were no data directly focused on this question with children close to the age of the children we tested.

4.1. Method

The 36 children in this experiment were grade 3 and grade 5 students ($\overline{X} = 9.29$ years; 16 girls, 20 boys) at a public school in New York City who participated in an after school program held at Barnard College, that investigated children's metacognitions and learning. They were treated in accordance with the APA guidelines.

The program and procedure were the same as those used in Experiments 1 and 2.

4.2. Results

4.2.1. Performance

Performance in the task was very good, and reflected the influence of the experimental manipulations, as given in Table 1, and as was seen with the two other groups of participants. An ANOVA showed the main effect of Condition to be significant, as expected, for hit rate ($F(5, 210) = 100.46$, $p < .001$, $MSe = 1.45$ $\eta_p^2 = .71$), false alarm rate ($F(5, 210) = 32.71$, $p < .001$, $MSe = .07$, $\eta_p^2 = .44$), and for d' ($F(5, 210) = 108.38$, $p < .001$, $MSe = 25.57$, $\eta_p^2 = .72$).

The mean total movement, in pixels, over the entire task was about the same as that of the college student, 3.11×10^4, s.d. = 2.88×10^4.

4.2.2. Judgments of performance

The children's JOP followed their performance curves. JOPs were highest for the Magic condition, next highest for the Control condition, and lower for both the Turbulence and Lag conditions (Table 1). An ANOVA showed that the main effect of Conditions was significant ($F(5, 210) = 37.52$, $p < .001$, $MSe = 13551.04$, $\eta_p^2 = .47$).

4.2.3. Relation of judgments of performance to performance

As is shown in Fig. 2 panel C, while children's JOP tracked their hit rate, unlike college students and older adults who were underconfident, the children were overconfident.

The correlations, for each participant, were also computed between their JOP and their hit rate. These correlations were above zero in all cases, with no participant scoring below zero. The mean correlation, over all participants was $r = .67$, which was different from zero ($t(35) = 19.47$, $p < .001$). Although the children's metacognitions were very respectable, and well above zero, their correlations were significantly lower than those of the college students ($r = .89$), $t(77) = 6.34$, $p < .001$).

4.2.4. Judgments of agency

The Pearson correlation between the children's JOPs and their JOAs was $r = .79$. A t-test of Fisher's transformed-correlations was performed, and was significantly greater than zero, ($t(35) = 13.64$, $p = .000$. The transformed children's values were also significantly different from college student's, such that the children's correlations were lower than were the college students' , $t(77) = 2.07$, $p = .04$.

In a 2×2 ANOVA comparing Type of Discrepancy and Amount of Discrepancy, the children showed no effect of Type of Discrepancy ($F < 1$), no effect of Amount of Discrepancy, ($F(35) = 1.27$, $p = .27$, $MSe = 80.76$, $\eta_p^2 = .04$) and no interaction between Type of Discrepancy and Amount of Discrepancy ($F < 1$). Thus, they were not sensitive to the Lag manipulation the way that the college students had been. However, they *were* sensitive to the loss of control, just as college students and the older adults had been. Both collapsed Turbulence scores ($\overline{X} = -6.66$; $t(35) = 2.88$, $p = .01$) and collapsed Lag scores ($\overline{X} = -6.65$; $t(35) = 2.89$, $p = .01$) had summary scores significantly lower than zero.

The most interesting finding with the children, however, was in the Magic condition, in which performance had been artificially enhanced by the computer program. Here, the children took full credit for the results. They did not evidence any sense of a lack of control. Instead the summary score comparing their JOAs to their JOPs was -0.6, a value that was nowhere close to being different from zero ($t(35) = 0.28$, $p = .78$). Fig. 5 illustrates these results.

4.2.5. Additional analyses

We conducted a 2 (Group, children or college students – between participants) $\times$ 2 (Type of Discrepancy, Turbulence or Lag – within participants) $\times$ 2 (Amount of Discrepancy (small or large – within participants) ANOVA on the summary agency scores given above, for children, and those for college students. There was an interaction between Group and Type of Discrepancy such that the college students discriminated Lag from Turbulence, whereas the children did not ($F(1, 77) = 4.57$, $p = .04$, $MSe = 97.13$, $\eta_p^2 = .06$). There was also a main effect of Type of Discrepancy ($F(1, 77) = 4.59$, $p = .04$, $MSe = 97.13$, $\eta_p^2 = .06$), but it was because of the adult results on this variable. The main effect of Group approached significance ($F(1, 77) = 3.29$, $p = .07$, $MSe = 505.55$, $\eta_p^2 = .04$,).

We also conducted a t-test on the Magic condition, between the children and the college students. There was a

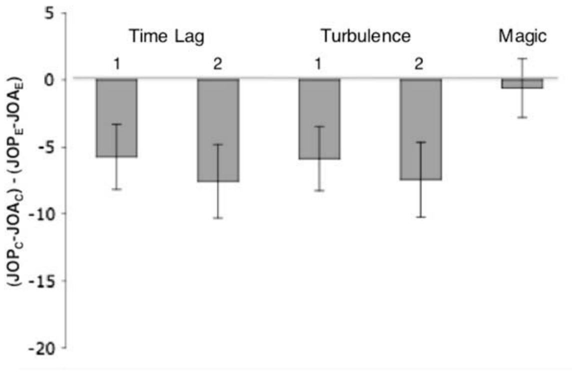

Fig. 5. Children's agency scores given by (JOP_C–JOA_C)–(JOP_E–JOA_E), where C refers to the control condition, and E refers to the experimental condition, respectively: Lag 1, Lag 2, Turbulence 1, Turbulence 2, or Magic. A negative score indicates that there was a correct perception of not being in control.

significant difference between the children and the college students in their summary agency scores in the Magic condition. The college students realized that the increased performance was not entirely due to them, whereas the children thought they had done it ($t(77) = 2.59$, $p = .01$).

4.3. Discussion

Children, in this experiment, were as good as the college students at picking up on their lack of agency in the Turbulence conditions (though they did not increase their judgments of agency, as did the college students, in the Lag condition.) But the most interesting thing about our children's results is that they apparently did not realize that they were not fully responsible for the favorable outcome, in the Magic condition. This outcome did not conform to any of our pre-existing hypotheses about what would happen, though in retrospect the results appear to follow some order – intermediate between not understanding agency, and having a fully developed adult sensibility. When the outcome was bad, the children realized that it was not their doing. When the outcome was good, the children took full credit for it. There was a conflation between the desire for the favorable outcome and their monitoring of their own behavior that made it so.

There are several lines of experimental data in younger children that presage these results. For example, in an experiment by Schult (1996, cited in Astington, 2001) children 3, 4 and 5 years old had to throw beanbags at colored buckets, first choosing which bucket they wished to aim at. Some of the buckets contained stickers, which the children collected to win the game. When the chosen bucket was hit, most children at all ages, claimed that they had intended to hit that bucket. However, when the chosen bucket was not hit, 3-year-old children tended to claim that they had been trying to hit that bucket under the condition that it contained a sticker. Older children showed this conflation of the outcome and their favorable intention to a much lesser extent, however. Phillips (l994, also cited in Astington, 2001) similarly, conducted a task in which children shot at colored cans, but disentangled intention and desire. Sometimes, even though the experimenter manipulated the conditions so that sometimes the intended can was hit, the desire (to get the prize) was not fulfilled. The 4-year-old children, but not the 5-year-olds, tended to say that they had intended to hit the other can, in this discrepant situation. A number of other tasks have shown similar results, but they are linguistically complicated, and this may qualify the interpretation. Furthermore, in all cases, the children who conflated desirable outcome with agency were much younger than those children studied in our paradigm. On the other hand, our paradigm was much more subtle than either of these tasks, and so may have revealed persistent differences in perceived responsibility for good outcomes, that more blatant tasks may have missed.

It was clear that the children understood the present task, and performed appropriately – denying control – when the result was unfavorable, that is when Turbulence *hurt* their performance. Their JOAs were not driven, in this case, only by the outcome (or by the magnitude of their JOPs). They also knew that something extraneous – the Turbulence – was intervening. In the case that the outcome was favorable, however, the children failed to take into account that something extraneous was intervening. Our data suggest that desire continues to have a complex, and rather self-serving effect on children's metacognitions of agency well into middle childhood.

5. General discussion

A summary and comparison of the three groups in this study is presented in Table 2. The college students showed excellent metacognitions of agency in all cases. When Turbulence was introduced, they were sensitive to the fact that they were less in control than their JOPs indicated. When a Lag was introduced, they knew that they were less in control than in the case when there was no distortion of control. However, they felt less out of control when the distortion was mediated by a temporal delay rule than when the same Amount of Discrepancy between where the mouse was and where the cursor on the screen showed it to be was randomly determined. When the X's were hit 'by Magic,' that is, when the person did not have to actually touch the X, but only come fairly close to it to be credited with a hit, the college-aged students were aware that their performance improved, but they did not take full credit for having caused this increase in performance. Thus, in the college students, it did not matter whether the loss of

Table 2
A summary of the agency results of the experiment for each of the three groups. 'Yes' means that the group recognized that they were not in full control, in the Turbulence, Lag, and Magic conditions, in which they were not in objectively in full control, and that they were less out of control in the Lag than in the Turbulence conditions.

Group	Lag	Turb	Magic	Distinguished Turb from Lag
College students	Yes	Yes	Yes	Yes
Older adults	Yes	Yes	Yes	No
Children	Yes	Yes	No	No

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control had a favorable or unfavorable outcome; they were aware of when they were in control and when they were not.

The healthy older participants, generally, were somewhat less sensitive in their JOAs to experimental manipulations that resulted in a loss of their control, relative to the college students. They were still significantly sensitive to distortions in control attributable to Turbulence, Lag and Magic, but they did not notice that they were more in control in the rule-mediated Lag condition than in the random Turbulence condition. There could be many reasons for the difference in overall sensitivity between college students and older adults, including the fact that the college students almost certainly had more experience in handling mouse controls on a computer. The possibility that the amount of experience that an individual has in a particular situation powerfully contributes to both their sensitivity to the parameters affecting performance in that situation and to their judgments about their own agency deserves intensive exploration in future work. Additionally, sheer motor control loss, and, in some cases a bit of shakiness, occurs with increasing age even in healthy older adults (although none of the older adults reported any muscular/motor impairment). So there might have just been more 'noise' in the systems of the older adults – making it more difficult for them to ascertain what responses were due to their own motor processes and which resulted from external manipulations.

Alternatively, the reason that older adults might have expressed feeling less out of control than their younger counterparts when noise and Turbulence were introduced may have been that elders have an attribution bias towards feeling and saying that they are in control (e.g., Lachman, 1985). Such a self-oriented attribution bias could account for the difference between younger and older adults in our results. Older adults may feel more responsible, in general, for what happens, than do younger people. The older adults' overall metacognitive monitoring – as evidenced by their judgments of their own performance – was excellent. Thus, the difference their metacognition of agency as compared to that of younger adults was probably not due to a deficit in general metacognitive monitoring ability (see, Hashtroudi, Johnson, & Chrosniak, l989; Hertzog & Hultsch, 2000). All told, the older adults, on all but the distinction between Lag and Turbulence, were sensitive to when they were and were not in control.

The children, also, were highly sensitive to the distortions of control that resulted in poorer performance. Like the older adults, they did not recognize the difference between the Lag conditions and the Turbulence conditions, though. Only college students appeared to reflect that they were less out of control in the Lag than the Turbulence condition. In both the Lag and the Turbulence cases, though, the children realized that they were not fully in control – and their ratings showed that they were able to monitor their own agency in this quite subtle task.

The exception to this general ability of the children to accurately monitor their own agency is an interesting one. When the outcome of the externally produced distortion improved their performance, in the Magic condition, the children did not realize that it was not they who had done it. This selective blind spot on agency monitoring suggests a kind of 'wish fulfillment' in the children. When the outcome of an external manipulation was unfavorable they were sensitive to putting the blame elsewhere. But when the outcome was favorable, they were quite willing to take the credit – even on this micro scale task – for themselves.

How did the four frameworks – the Wegner (2003) view, the Johnson et al. (1993) elaboration of the MEM model, the forward model (Frith et al., 1999), and the Kantian rule-mediation view – fare? Both the Wegnerian view and the MEM model propose that people have overall goals and intentions that come into play in making assessments of agency. Insofar as those goals are fulfilled, these frameworks predict that people should claim agency. The present experiments offer broad support for this idea, which is strongly borne out by the high correlations between JOP and JOA. Overall, when people at all ages thought that they had done well on the task, they ascribed high self-agency. When they perceived that performance was poor, they ascribed low agency. This overarching determinant, however, cannot account for the fine-grained detail of the results in these experiments.

The simple idea that when what an individual intends to have happen, happens, he or she claims agency, cannot account for why the young and the older adults both fail to take full credit for the Magic. The adults apparently realized (correctly) that although their performance was quite high, it was not entirely due to them. This idea, that the favorableness of the outcome bears a direct relation to feelings of agency, in and of itself also cannot account for why the children were different on this dimension, but it is possible that children were using only this global dimension, and not using more fine grained monitoring of action plans. Emotional factors, such as those stressed in the Johnson et al. (1993) version of the MEM model, may provide some hints into this difference between children and adults, and are certainly worth further exploration. It is also possible that feeling in control is not just a lack of feeling out of control. Instead, the feeling of being in control may be triggered by an entirely different state or mental system, than the absence of being out of control. Feelings of being in control may, for example, be reward modulated and these feelings may be different in children and adults.

Only the forward model (e.g., Frith et al., 1999) accounts in any kind of detail for why people recognize that they are more out of control than their JOPs suggest in the Turbulence, the Lag, and the Magic conditions. This model points to a matching operation that monitors the fit between the person's detailed action plan and the outcome. In the Turbulence condition, since the computer program added noise to the cursor, the individual's motor plan and the path of the cursor on the screen which gives the outcome of the action would not match perfectly, and so the mismatch or 'out of control' signal would be triggered. The same mismatch signal would be generated in the Lag condition. The forward model can also account for the finding that young and older adults both resist taking full credit for Magic, even though the outcome matches well to their presumed overall expectations and goals. In this case, too, the motor plan and detailed outcome would be mismatched.

The model does not directly shed light on all of the differences seen on these variables, across groups, however. Does the discrepancy detection mechanism only work some of the time in children, for example? Why would it work for Turbulence, with the children, but not for Magic? The forward model also does not address the finding of a difference, in the college students, in their attributions of agency in the Turbulence and time Lag conditions. In these two cases, the Amount of Discrepancy introduced externally is the same, and yet the college student's response to the Lag condition was different than their response to the Turbulence condition. The forward model can explain why there was no difference in the agency judgments between these two conditions in the older adults and the children, but it cannot explain why the younger adults showed a difference in their agency judgments between these two.

Although the Kantian perspective does not provide detailed insight into the overall findings – unlike the forward model, or the idea that our perception of our performance drives our feelings of agency – it, nevertheless, provides a suggestion of an explanation for why the young adults were able to pick up on the time Lag manipulation, while neither the children nor the older adults did so. This differential sensitivity to the fact that there was a rule relating action and effect suggests that top-down processes related to the construal of the situation can influence JOA and may vary among people. Presumably only the young adults entertained the possibility that the discrepancy, in the Lag condition, might not be due to random noise, but rather that there might be a rule that related to their actions their effect. Neither the children nor the older adults gave any indication that they had picked up on such a rule. Perceiving the mediating rules that may span a causal relation between and individual's action and the outcomes in the world seems crucial for the evaluation of metacognition of agency. If one can see how one's own action may have had an effect one is much more likely to claim agency than if the relation is not discerned. Such top-down influences comprise a largely unexplored domain that may be of critical importance in understanding not only normal metacognition of agency but also pathologies in this central aspect of human mental life.

While our intuitions suggest that our knowledge of our own agency is central and universally unassailable, the results presented here belie that intuition. There are interesting and systematic differences among people in how sensitive they are to distortions in their actual control. The data showed that college students were highly sensitive to violations of agency, whether those violations helped or hurt their perceived performance. They also picked up on the new manipulation introduced in this study in which control was time lagged – attributing less of a violation of agency than a matched Turbulence condition. Thus, the college students did a very good job of knowing when they were in control and when they were not. This finely tuned sensitivity to the conditions in which one is and is not in control was not obtained to the same extent, either with older adults or with children. The older adults were less sensitive, across the board, to a lack of control. The children were highly sensitive to a lack of control when the external source of the distortion impaired their performance, but they were completely insensitive when the external source helped performance.

These results suggest that people's metacognitions about the extent to which they are in control may be determined by a set of heuristics. One heuristic that contributes to these judgments appears to be the perceived goodness of performance. All three age groups seemed to use this heuristic, as witness the high correlations between judgments of performance and judgments of agency. A second is the detection of a discrepancy between the person's detailed motor plan and the outcome of the resultant action. Again, all three groups appeared to use this cue in the cases of Turbulence and Lag, and the young and older adults also presumably used it in the Magic condition. A third heuristic appeared to be whether the outcome matched the person's wishes. The children may have relied on this heuristic in the Magic condition. A fourth may be the concordance of the outcome with the top down theory the person holds of the situation. These theories appeared to be different, for the Lag condition, between the young adult group and the two other groups. In general, then, these heuristics, and others yet unexplored, may all be recruited when people make a judgment of their own agency. Interestingly, the present results indicate that the various sources contributing to the JOA are weighted differently by people of different ages.

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