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Dissociating intuitive physics from intuitive psychology: Evidence from Williams syndrome



Frederik S. Kamps^a, Joshua B. Julian^b, Peter Battaglia^c, Barbara Landau^d, Nancy Kanwisher^c, Daniel D. Dilks^{a,*}

^a Department of Psychology, Emory University, Atlanta, GA 30322, United States

^b Department of Psychology, University of Pennsylvania, Philadelphia, PA 19104, United States

^c Department of Brain and Cognitive Sciences, Massachusetts Institute of Technology, Cambridge, MA 02139, United States

^d Department of Cognitive Science, Johns Hopkins University, Baltimore, MD 21218, United States

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ABSTRACT

Prior work suggests that our understanding of how *things* work (“intuitive physics”) and how *people* work (“intuitive psychology”) are distinct domains of human cognition. Here we directly test the dissociability of these two domains by investigating knowledge of intuitive physics and intuitive psychology in adults with Williams syndrome (WS) – a genetic developmental disorder characterized by severely impaired spatial cognition, but relatively spared social cognition. WS adults and mental-age matched (MA) controls completed an intuitive physics task and an intuitive psychology task. If intuitive physics is a distinct domain (from intuitive psychology), then we should observe differential impairment on the physics task for individuals with WS compared to MA controls. Indeed, adults with WS performed significantly worse on the intuitive physics than the intuitive psychology task, relative to controls. These results support the hypothesis that knowledge of the physical world can be disrupted independently from knowledge of the social world.

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1. Introduction

Humans rapidly and accurately understand complex scenarios involving physical objects and social beings. For example, in a brief glance we understand whether a precarious stack of books will fall or whether a person is engaged in conversation with someone else. Philosophers and psychologists have suggested that these remarkable human capacities are supported by distinct cognitive mechanisms: one for understanding how *things* work, known as “intuitive physics” or “folk physics”, and a second for understanding how *people* work, known as “intuitive psychology” or “folk psychology” (Carey, 1985; Dennett, 1987; Leslie, 1995; Wellman & Inagaki, 1997). These systems are distinguished conceptually by the kinds of information they must represent. Intuitive physics supports reasoning about inanimate objects based on physical properties of objects (e.g., size, weight, etc.) and external forces (e.g., other objects, gravity, etc.) that may be acting upon them. By contrast, intuitive psychology supports reasoning about animate agents based on the

information known to be available to the agent (e.g., what or who they can currently see, what they have or have not been told, etc.) and the agent’s internal goals, intentions, and desires.

However, beyond conceptual arguments for the distinction between intuitive physics and intuitive psychology, relatively little empirical evidence exists to support the independence of these cognitive domains. Indeed, while many studies have focused on questions within the domain of either intuitive physics or intuitive psychology, far fewer have directly compared the two. If intuitive physics and intuitive psychology are independent cognitive domains, then it should be possible to find cases of selective impairment in one domain, but not the other. To this end, a number of studies have explored intuitive physics and intuitive psychology in autism spectrum disorders (ASD) (Baron-Cohen, Leslie, & Frith, 1986; Baron-Cohen, Wheelwright, Spong, Schill, & Lawson, 2001; Binnie & Williams, 2002; Charman & Baron-Cohen, 1995; Leslie & Thaiss, 1992). Such studies reveal that individuals with ASD are impaired at intuitive psychology tasks relative to both typically developing controls and individuals with comparable, nonspecific developmental disorders (e.g., Down’s syndrome), but nevertheless show typical or even superior performance on intuitive physics tasks. This single dissociation provides important initial evidence

* Corresponding author at: Department of Psychology, Emory University, 36 Eagle Row, Atlanta, GA 30322, United States.

E-mail address: dilks@emory.edu (D.D. Dilks).

that intuitive physics and intuitive psychology may be independent. Critically, however, if intuitive physics and intuitive psychology are truly independent, then it should also be possible to find cases of impaired intuitive physics coupled with spared intuitive psychology. Indeed, without such evidence, it could still be the case that a single mechanism (e.g., for causal inference) underlies both kinds of reasoning, and that intuitive psychology is simply a more difficult or complex case than intuitive physics.

Here we search for this complementary profile (i.e., impaired intuitive physics, spared intuitive psychology) by studying intuitive physics and intuitive psychology abilities in adults with Williams syndrome (WS). WS is a genetic developmental disorder caused by a hemizygous microdeletion of ~28 genes on chromosome 7q11.23 (Ewart et al., 1993). Strikingly, although WS involves moderate intellectual disability (average IQ is around 65; Mervis & John, 2010), this highly specific genetic deletion does not affect all domains equally. For example, people with WS are severely impaired compared to typically developing mental-age matched (MA) controls on a variety of visual-spatial tasks, such as block construction (Hoffman, Landau, & Pagani, 2003), spatial memory (Vicari, Bellucci, & Carlesimo, 2003), visually-guided action (Atkinson et al., 1997; Dilks, Hoffman, & Landau, 2008), and multiple object tracking (O’Hearn et al., 2005). By contrast, WS individuals perform similarly to MA controls—and sometimes even chronological age matched controls—on a variety of social tasks, including face recognition (Tager-Flusberg, Plesa-Skwerer, Faja, & Joseph, 2003), biological motion perception (Jordan, Reiss, Hoffman, & Landau, 2002), emotion expression (Tager-Flusberg & Sullivan, 2000), and theory of mind (Karmiloff-Smith, Klima, Bellugi, Grant, & Baron-Cohen, 1995; Tager-Flusberg, Boshart, & Baron-Cohen, 1998; Tager-Flusberg & Sullivan, 2000). Furthermore, people with WS are described as showing a strong interest in the social world (Klein-Tasman & Mervis, 2003; Tager-Flusberg et al., 1998), and have even been described as “hypersocial” (Jarvinen, Korenberg, & Bellugi, 2013).

Insofar as intuitive physics is an inherently visual-spatial process, while intuitive psychology is inherently social, the contrasts in performance across a variety of spatial and social tasks in WS above suggest that intuitive physics and intuitive psychology may likewise be differentially susceptible to damage in this genetic disorder. Indeed, recent studies of WS individuals suggest that specific genes within the WS deletion play distinct roles in the overall cognitive profile; for example, *LIMK-1* has been related to visual-spatial deficits, while *GTF2I* has been related to social aspects of the disorder (Dai et al., 2009; Frangiskakis et al., 1996; Sakurai et al., 2011). Thus, considering both the specific cognitive and genetic dissociations found in this disorder, it is possible that adults with WS will perform disproportionately worse on an intuitive physics task than on a comparable intuitive psychology task, relative to MA controls. To test this prediction, WS adults and MA control participants completed two tasks, each involving a high-level judgment made after viewing a complex, naturalistic six-second video. In the intuitive physics task, participants observed 6 s videos of unstable towers of blocks, and were asked to judge in which of two directions the tower would fall (e.g., “toward the red side or green side?”).¹ In the intuitive psychology task,

participants observed 6 s videos of children playing with toys who were either interacting with an off-screen “friend”, or not, and were asked to judge whether the child was playing alone or with someone else (e.g., “one person or two people?”).

Finally, following our primary analysis testing the prediction above, we conducted additional analyses addressing previous arguments that WS cannot be used as a neuropsychological model of the typical cognitive system. This argument has been leveraged on the basis that WS individuals might develop differently from typically developing children from birth, leading to qualitative differences in cognitive processes underlying their behavior (Karmiloff-Smith, 1997). Thus, in WS, it might be possible that any observed decrement in performance on the intuitive physics task results from a *qualitatively* different pattern of performance from the MA controls (e.g., WS might show a distinct pattern of performance across the trials, reflecting a distinct underlying mechanism), rather than a *quantitatively* different pattern of performance (e.g., WS might show the same overall pattern of performance across the trials as MA controls, but at reduced accuracy, reflecting a similar underlying mechanism that is less developed in the case of WS) (Musolino & Landau, 2012). To test this possibility, we compared detailed patterns of performance in people with WS compared to MA controls (around 8 years old), as well as an even younger group of typically developing children (i.e., 4 year olds)—an age at which WS adults have been observed to perform comparably on other tasks on which they show deficits (Bellugi, Bihrlé, Neville, Doherty, & Jernigan, 1992; Dilks et al., 2008).

2. Methods

2.1. Participants

Sixteen adults with WS (9 females), 16 MA controls (9 females), and 16 typically developing 4 year olds (10 females) participated in the study. Participant characteristics are presented in Table 1. The WS adults were recruited through the Williams Syndrome Association, and all had been positively diagnosed by a geneticist and the FISH test, confirming a deletion in the classic WS region of chromosome 7. All adult participants and legal guardians of child participants gave informed consent.

Participants were tested on a standardized intelligence test, the Kaufman Brief Intelligence Test (KBIT; Kaufman & Kaufman, 1990). This test yields an overall IQ score, as well as scores for two components, Verbal and Non-verbal (Matrices). The Verbal subtest requires participants to match words or descriptions to pictures, and the Matrices subtest requires participants to judge which objects or patterns “go together”. Each WS adult was individually matched to a typically developing control participant based on raw scores for the verbal and nonverbal subtests (Table 1). Matching was done as closely as possible, with a mode of 4 points difference for the verbal match (max difference = 8, N = 2) and a mode of 3 points difference for the nonverbal match (max difference = 12, N = 1). As a result of this procedure, no significant difference was found between the two groups for either verbal ($t_{(30)} = 0.55$, $p = 0.58$, $d = 0.20$) or nonverbal raw scores ($t_{(30)} = 0.44$, $p = 0.66$, $d = 0.16$).

2.2. Design, stimuli, and procedure

Participants performed two tasks: an intuitive physics task, in which they judged the direction in which an unstable tower of blocks was likely to fall, and an intuitive psychology task, in which they judged whether or not a child was playing/interacting with an off-screen “friend”. The order of tasks was counterbalanced across participants. Both tasks were presented using custom software

¹ We used this task as a representative measure of intuitive physical reasoning for three reasons. First, this task strongly and preferentially modulates cortical regions that are also activated by a variety of other intuitive physics tasks (Fischer, Mikhael, Tenenbaum, & Kanwisher, 2016). Second, computational models using probabilistic simulations of Newtonian mechanics closely capture human performance both on this task and many other intuitive physics tasks (Battaglia, Hamrick, & Tenenbaum, 2013; Hamrick, Battaglia, & Tenenbaum, 2011). Third, this task does not rely on language abilities, unlike other intuitive physics tasks (Baron-Cohen et al., 2001, 2003), which is crucial for the study of WS individuals whose relatively spared language abilities could mask any potential intuitive physics impairment.

Table 1
Participant characteristics for WS adults and MA controls.

	WS adults			MA controls		
	M	SE	Range	M	SE	Range
Chronological age	24.06	1.4	18–37	8.87	0.3	6.31–9.93
Verbal KBIT (raw score)	66.25	3.19	39–83	64	2.51	42–79
Verbal KBIT (standard score)	76.56	2.89	51–92	119.88	2.34	101–138
Non-verbal KBIT (raw score)	28.63	1.74	14–38	29.75	1.86	17–38
Non-verbal KBIT (standard score)	80.88	4.09	40–100	110.13	3.97	80–129
KBIT composite IQ	75.75	3.27	43–93	117.56	2.98	90–133

written for the Matlab Psychophysics Toolbox (Brainard, 1997), and required participants to make simple, binary judgments on 6 s movies. All participants viewed stimuli on a 20.5" × 11.5" LCD monitor, while seated at a distance of approximately 30".

In the intuitive physics task, participants were shown 6 s video clips of unstable towers of blocks (Fig. 1A). The stimuli were adapted versions of those used in Battaglia et al. (2013), and were presented at a size of approximately 16° × 12° visual angle. In each video, the ground plane was divided in half, with one half colored red, and the other half colored green. The video revolved around the tower of blocks such that the tower could be observed from all sides across the duration of the video. Participants were then asked to judge whether the tower would fall on the red side or the green side. Responses were given orally, and recorded by the experimenter via keypress. Each participant completed a training phase, followed by a testing phase. In the training phase, participants received feedback after each response, including both a video showing how the pile of blocks would actually fall to the ground, and explicit feedback about whether or not their response was correct. The training phase included 5 trials. All participants passed the training phase. Next, in the testing phase, participants were told they would no longer receive feedback, and to simply give their best guess. The testing phase included 54 trials, and trials were presented in random order. Finally, in order to verify that participants understood and were paying attention to the task, the testing phase was evenly interspersed with 6 “catch” trials in which the direction of instability was extremely salient, thus measuring basic task understanding and attentiveness.

In the intuitive psychology task, participants were shown 6 s video clips of children playing with toys (Fig. 1B). The stimuli were the same as those used in Balas, Kanwisher, and Saxe (2012), and were presented at a size of approximately 19° × 11° visual angle. In each video, a single child was shown playing with Legos while seated at a table. Participants were told to watch the video closely, and then were asked to judge whether each child was playing alone or with a “friend” who was out of view of the camera. Prior to testing, the experiment was explained in detail using an example stimulus in which the “friend” was visible (i.e., not cropped out of view), followed by the same stimulus, but with the “friend” cropped out of view. This example stimulus allowed participants to understand the physical set-up of the experiment (i.e., to show how the child could be playing with a friend, even if the friend could not be seen in the video). During the example trial, participants were screened for their understanding of the task using two questions: (i) Is this person’s friend still here even though we can’t see him or her through this window? and (ii) Can this person still play with their friend even when we can’t see him or her? All participants were able to answer these questions correctly. In the testing trials, participants were reminded that they would never be able to see the friend, and to simply give their best guess. The testing phase included 28 trials, and trials were presented in random order. In each trial, a movie played for 6 s, and was immediately followed by a response screen containing the prompt “one or two?” which remained visible until the participant responded. Responses were given orally, and recorded by the experimenter via keypress.

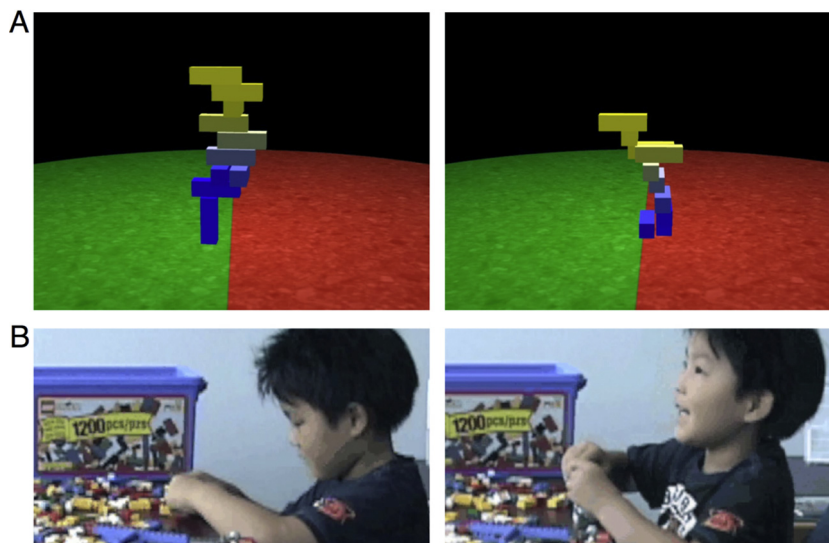


Fig. 1. (A) Intuitive physics task. Participants watched 6 s videos of unstable towers of blocks and had to judge whether the tower would fall on the red side (e.g., left image) or the green side (e.g., right image). (B) Intuitive psychology task. Participants watched 6 s videos of children playing with toys and had to judge whether the child was playing alone (e.g., left image) or with an off-screen friend who could not be seen (e.g., right image).

3. Results

If intuitive physics and intuitive psychology are independent cognitive domains, then we predict that WS adults will show a greater impairment on an intuitive physics task compared to an intuitive psychology task, relative to MA controls. Consistent with this prediction, the WS adults performed significantly worse on the intuitive physics task compared to the intuitive psychology task ($t_{(15)} = 5.05$, $p < 0.001$, $d = 1.27$, $CI = [0.10, 0.24]$) (Fig. 2). Fourteen out of 16 participants showed this effect (i.e., performing numerically worse on the intuitive physics task compared to the intuitive psychology task) (Fig. 2). By contrast, the MA controls showed the opposite pattern, performing significantly better on the intuitive physics task compared to the intuitive psychology task ($t_{(15)} = 2.90$, $p = 0.01$, $d = 0.74$, $CI = [0.02, 0.12]$). Twelve out of 16 participants showed this effect (i.e., performing numerically better on the intuitive physics task than the intuitive psychology task) (Fig. 2). Crucially, directly comparing across groups, a 2 (Group: WS adults, MA controls) \times 2 (Task: intuitive physics, intuitive psychology) mixed-model ANOVA revealed a significant interaction ($F_{(1,30)} = 33.51$, $p < 0.001$, $\eta_p^2 = 0.53$, $CI = [0.16, 0.33]$) (Fig. 2). Bonferroni corrected post hoc comparisons revealed that the WS adults performed significantly worse than the MA controls on the intuitive physics task ($p < 0.001$, $CI = [0.14, 0.29]$), but similar to the MA controls on the intuitive psychology task ($p = 0.51$, $CI = [-0.05, 0.10]$). Taken together, these results demonstrate that WS adults show a disproportionate impairment in the domain of intuitive physics, consistent with the hypothesis that intuitive physics and intuitive psychology are independent cognitive domains.

Might this pattern of results reflect a failure of the WS adults to understand or pay attention during the intuitive physics task, rather than a disproportionate impairment in the domain of intuitive physics? We do not think so for three reasons. First, all the WS adults passed the training phase of the intuitive physics task, verifying they understood the task. Second, a one-sample t -test revealed that the overall performance of WS adults on the intuitive physics task was significantly above chance ($t_{(15)} = 2.72$, $p = 0.02$, $d = 0.68$, $CI = [0.02, 0.14]$), indicating that WS adults both understood and were paying attention, and not simply guessing, during the intuitive physics task. Moreover, even when those participants who performed at or below chance (i.e., 5 out of the 16) were removed from the analysis, the 2 (Group: WS adults, MA controls) \times 2 (Task: intuitive physics, intuitive psychology) interaction remained significant ($F_{(1,25)} = 22.39$, $p < 0.001$, $\eta_p^2 = 0.47$, $CI = [0.13,$

0.33]), demonstrating that our findings were not driven by a subset of participants who might not have understood or paid attention during the intuitive physics task. Third, interspersed throughout the intuitive physics task were six “catch” trials in which the direction of instability of the block tower was extremely salient, allowing us to probe task understanding and attention specifically. WS adults responded correctly on 84.44% of catch trials, well above chance ($t_{(15)} = 7.83$, $p < 0.001$, $d = 1.96$, $CI = [0.25, 0.44]$). Again, even when we included only WS Adults who responded correctly on 100% of catch trials (i.e., 8 out of the 16), the 2 (Group: WS adults, MA controls) \times 2 (Task: intuitive physics, intuitive psychology) interaction remained significant ($F_{(1,22)} = 20.05$, $p < 0.001$, $\eta_p^2 = 0.48$, $CI = [0.13, 0.36]$). Taken together, these analyses indicate that the lower performance on the intuitive physics task did not reflect a failure to understand or pay attention during the task, but rather reflects a disproportionate impairment in the domain of intuitive physics.

But does our finding that WS adults show impaired performance in intuitive physics, yet relatively spared performance in intuitive psychology, truly reflect dissociable cognitive systems in typical individuals? It has been argued that WS cannot be used as a neuropsychological model of the typical cognitive system, since cognition in WS may be supported by qualitatively different underlying mechanisms from those in typically developing individuals (Karmiloff-Smith, 1997). In the absence of specific proposals for these alternative mechanisms, our hypothesis is that despite the findings above that WS individuals perform *quantitatively* worse on intuitive physics than intuitive psychology tasks relative to MA controls, WS individuals will nevertheless perform the intuitive physics task *qualitatively* similar to typically developing individuals—suggesting that WS individuals employ a qualitatively similar mechanism. To address this possibility of qualitative differences in WS individuals, we examined more detailed patterns of performance of the WS adults and MA controls on the intuitive physics task by dividing trials into three difficulty levels (easy, medium, and hard), previously determined by Battaglia et al. (2013). For the WS adults, a three-level repeated measures ANOVA revealed a significant main effect ($F_{(2,30)} = 11.54$, $p < 0.001$, $\eta_p^2 = 0.44$). Bonferroni corrected post hoc comparisons revealed that WS adults were significantly more accurate on both the easy and medium trials compared to the hard trials (easy vs. hard: $p = 0.02$, $CI = [0.02, 0.28]$; medium vs. hard: $p = 0.002$, $CI = [0.07, 0.30]$), but were similarly accurate on the easy and medium trials ($p = 0.84$, $CI = [-0.11, 0.05]$). For the MA controls, a similar pattern of performance was found: a three-level repeated measures ANOVA revealed a significant main effect ($F_{(2,30)} = 19.17$, $p < 0.001$, $\eta_p^2 = 0.56$). Bonferroni corrected post hoc comparisons revealed that MA controls, like the WS adults, were significantly more accurate on both the easy and medium trials compared to the hard trials (easy vs. hard: $p < 0.001$, $CI = [0.09, 0.26]$; medium vs. hard: $p = 0.004$, $CI = [0.04, 0.23]$), but were similarly accurate on the easy and medium trials ($p = 0.25$, $CI = [-0.02, 0.10]$). While these findings suggest that the WS adults and MA controls perform the tasks in a qualitatively similar way, we next tested this suggestion directly. A 2 (Group: WS adults, MA controls) \times 3 (Difficulty: easy, medium, hard) mixed-model ANOVA revealed no significant interaction ($F_{(2,60)} = 1.07$, $p = 0.35$, $\eta_p^2 = 0.03$), indicating that the pattern of performance was indeed quantitatively, not qualitatively, different between the two groups (Fig. 3). However, caution should be taken in interpreting the lack of an effect (i.e., no significant group \times difficulty interaction), and as such, we conducted an additional permutation F-test, which may be more powerful than ANOVA when sample size is relatively small, as might be the case here. To do so, we compared our observed F statistic for the group \times difficulty interaction against a distribution of F statistics generated by randomly shuffling the accuracy data between

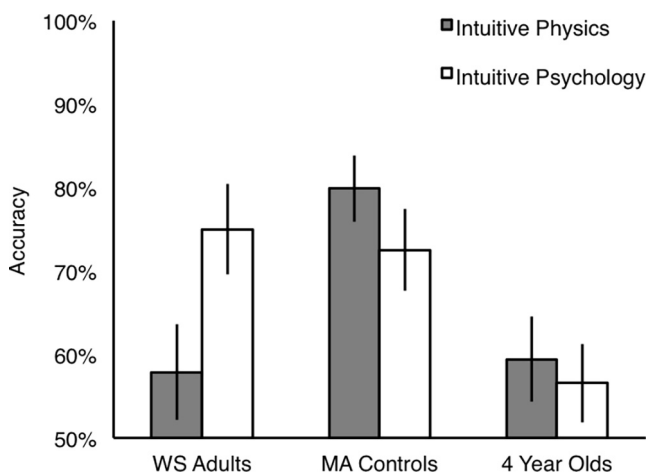


Fig. 2. Average performance of WS Adults, MA Controls (average age = 8) (Experiment 1), and 4 year olds (Experiment 2) on the Intuitive Physics and Intuitive Psychology tasks. Error bars indicate 95% confidence intervals.

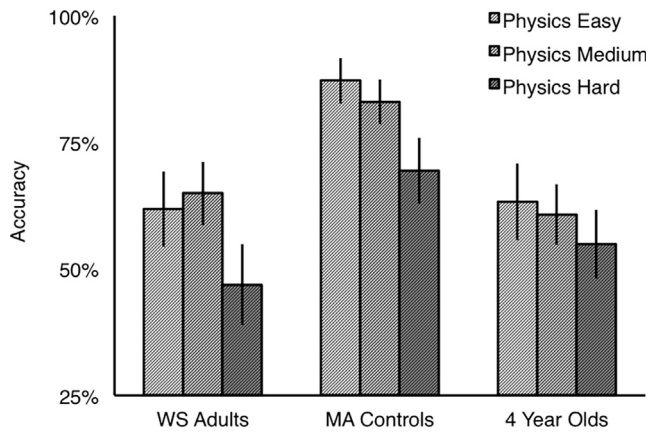


Fig. 3. Average performance of WS Adults, MA Controls (average age = 8), and 4 year olds on each difficulty level (easy, medium, hard) of the Intuitive Physics task. Error bars indicate 95% confidence intervals.

groups and conditions across 10,000 permutations. This analysis also failed to reveal a significant group \times difficulty interaction ($p = 0.35$). Taken together, across multiple tests, we found no difference between the detailed patterns of performance of the WS adults and MA controls on the intuitive physics task. This finding suggests that the WS impairment in intuitive physics reflects a similar underlying mechanism that is less developed in WS adults compared to typically developing 8 year olds, and begins to validate WS as a plausible neuropsychological model of the typical cognitive system.

An even stronger test of the hypothesis that WS is characterized by a quantitative (but not qualitative) impairment in intuitive physics would be to evaluate whether the performance of WS adults on the intuitive physics task is similar to the performance of typically developing children at an even earlier time point in development than that tested in our MA controls. We therefore compared the performance of WS adults to that of typically developing 4 year olds. A 2 (Group: WS adults, 4 year olds) \times 2 (Task: intuitive physics, intuitive psychology) mixed-model ANOVA revealed a significant interaction ($F_{(1,30)} = 18.20$, $p < 0.001$, $\eta_p^2 = 0.38$, $CI = [0.10, 0.29]$) (Fig. 2). Bonferroni corrected post hoc comparisons revealed that the WS adults performed similarly to the 4 year olds on the intuitive physics task ($p = 0.72$, $CI = [-0.09, 0.07]$), but, not surprisingly, significantly better on the intuitive psychology task ($p < 0.001$, $CI = [0.11, 0.26]$) (Fig. 2).

Next, to test whether WS adults and 4 year olds perform the task in a qualitatively similar way, we investigated the pattern of responses of WS adults and 4 year olds across easy, medium, and hard trials on the intuitive physics task. Interestingly, for the 4 year olds, a three-level repeated measures ANOVA did not reveal a significant main effect ($F_{(2,60)} = 2.27$, $p = 0.12$, $\eta_p^2 = 0.13$), unlike the WS adults, who did show significant difference across difficulty levels (see analysis above). While these findings suggest that WS adults and 4 year olds might perform the intuitive physics task differently, crucially, comparing across these groups directly, a 2 (Group: WS adults, 4 year olds) \times 3 (Difficulty: easy, medium, hard) mixed model ANOVA revealed no significant interaction ($F_{(2,60)} = 2.31$, $p = 0.11$, $\eta_p^2 = 0.07$), indicating that the pattern of performance was in fact similar between WS adults and 4 year olds. Next, to confirm this pattern of results, we again conducted a permutation F-test. Consistent with the ANOVA above, the permutation F-test failed to reveal a significant group \times difficulty interaction ($p = 0.11$). Thus, across these analyses, we found no evidence that WS adults and 4 year olds perform the task differently. Taken together, the qualitative similarity in performance between the WS adults and both typically developing groups (i.e., the 4 year

olds and MA controls) supports the idea that WS and typically developing individuals perform the intuitive physics task using a qualitatively similar underlying mechanism—albeit with WS adults achieving accuracy levels similar to those of much younger children—confirming the validity of WS as a neuropsychological model of the typical cognitive system, at least in the tasks used here.

Finally, we examined the typical development of intuitive physics and intuitive psychology by comparing the 4 year olds to the MA controls, who were on average 8 years old. A 2 (Group: 4 year olds, MA controls) \times 2 (Task: intuitive physics, intuitive psychology) mixed-model ANOVA revealed a significant main effect of group ($F_{(1,30)} = 44.93$, $p < 0.001$, $\eta_p^2 = 0.60$, $CI = [0.13, 0.24]$)—with performance on both tasks increasing with age—as well as a significant main effect of task ($F_{(1,30)} = 6.12$, $p = 0.02$, $\eta_p^2 = 0.17$, $CI = [0.01, 0.09]$)—with both groups performing better on the intuitive physics than the intuitive psychology task. However, we did not observe a significant group \times task interaction ($F_{(1,30)} = 1.13$, $p = 0.30$, $\eta_p^2 = 0.04$, $CI = [-0.13, 0.04]$) (Fig. 2). Similarly, a permutation F-test (in which we compared our observed F statistic for the group \times task interaction against a distribution of F statistics generated by randomly shuffling the accuracy data between groups and tasks across 10,000 permutations) also failed to reveal a significant group \times task interaction ($p = 0.29$). Thus, across multiple tests, we found no evidence of differential development of either intuitive physics or intuitive psychology between the ages of 4 and 8 years old. Of course, given the hypothesis of dissociable cognitive systems for intuitive physics and intuitive psychology, we would predict differential development between the two systems on ages younger than those tested here. Future research will investigate this possibility.

4. Discussion

The present study reveals a dissociation between the domains of intuitive physics and intuitive psychology in the case of WS, thus demonstrating that understanding of how things work (i.e., intuitive physics) can be disrupted independent of understanding of how people work (i.e., intuitive psychology). Specifically, adults with WS, a genetic developmental disorder, performed significantly worse than MA matched controls on a task assessing understanding of physical interactions, but similar to MA matched controls on a task assessing understanding of social interactions. Further analyses comparing detailed patterns of performance on the intuitive physics task revealed that despite their impairment, WS individuals performed the task in a qualitatively similar manner to typically developing individuals. While it is always possible that there may be some other measure that reveals a qualitative difference across groups, our analyses revealed only quantitative, not qualitative differences. This finding provides important support for the validity of WS as a neuropsychological model of the typical cognitive system.

Prior work had found a single dissociation between intuitive physics and psychology in the case of ASD, where ASD individuals show a selective impairment in intuitive psychology, but not intuitive physics. For example, individuals with ASD show impaired performance on false belief tasks, but not comparable false photo, model, or map tasks (Charman & Baron-Cohen, 1995; Leslie & Thaiss, 1992); picture sequencing tasks based on psychological states, but not causal-mechanical states (Baron-Cohen et al., 1986); tasks requiring participants to perceive mental states in pictures of the eye region of the face, but not multiple choice folk physics tests (Baron-Cohen et al., 2001), and self-report questionnaires measuring “empathizing” (i.e., how we understand and predict the social world, analogous to intuitive psychology), but not on comparable questionnaires measuring “systemizing” (i.e., how we

understand and predict the inanimate universe, analogous to intuitive physics) (Baron-Cohen, Richler, Bisarya, Gurunathan, & Wheelwright, 2003). Critically, however, this single dissociation leaves open the possibility that both intuitive physics and psychology draw on a more general system (e.g., for causal reasoning), and that intuitive psychology tasks simply involve more complex reasoning than intuitive physics tasks. Our finding that intuitive physics is disproportionately impaired in WS rules out this complexity account, strengthening the evidence for a dissociation between these two systems. Interestingly, these findings potentially further support the broadly held view that ASD and WS are mirror opposite conditions, given that the obvious profiles of ASD and WS tend to differ, as in the case of intuitive physics and intuitive psychology. However, this notion is likely too simplistic, given that there are a number of tasks on which WS and ASD individuals perform similarly (e.g., some ASD children, like WS individuals, have fluent language and well-functioning syntax), and that ASD is a heterogeneous disorder with poorly understood subgroups, some of which do not show the mirror opposite profile of WS. Indeed, the unraveling of genetics and cognition has a long way to go before the precise genotypic and phenotypic relationship between these disorders is fully understood.

Our finding that intuitive physics is disproportionately disrupted in WS suggests that this ability may be supported by a specialized cognitive system for intuitive physical reasoning (Carey & Spelke, 1994; Leslie, 1995). Our findings also suggest that physical reasoning may be supported by specialized neural systems (perhaps located in parietal cortex, consistent with findings that WS individuals show reduced grey matter and reduced sulcal depth in and around the intraparietal sulcus; Meyer-Lindenberg, Mervis, & Berman, 2006), similar to the specialized neural systems that have been identified for aspects of social perception and reasoning, including face perception (Kanwisher, McDermott, & Chun, 1997) and theory of mind (Saxe & Kanwisher, 2003). Indeed, recent work has revealed a set of cortical regions (including regions in the parietal lobe and premotor cortex) that respond preferentially when participants reason about and predict physical events compared to when participants reason about similar, non-physical events (Fischer et al., 2016).

But might the known visual-spatial deficits in WS explain our findings? We see two possible ways that a visual-spatial deficit outside the intuitive physics system could potentially account for our findings. One possible alternative account for our findings is that WS adults cannot accurately represent the spatial arrangement of the blocks that make up the tower before judgments are made about the direction in which the tower will fall, and it is this impairment that leads to their pattern of worse performance than MA controls, rather than an impairment in intuitive physics per se. This alternative account seems unlikely, given many studies showing that visual-spatial perception tasks are not generally impaired in WS adults relative to MA controls. For example, WS individuals show preserved ability to match perceptual configurations in (i) the classic Navon task, which involves perceiving how a set of smaller letters is arranged to make up a larger letter (e.g., a series of small “B’s” arranged as a large letter “A”) (Farran, Jarrold, & Gathercole, 2003); (ii) tasks requiring visual-spatial grouping of objects (Pani, Mervis, & Robinson, 1999); and (iii) visual illusions that rely on implicit visual-spatial integration, including the Ponzo, Muller-Lyer, Kaniza, and Ebbinghaus illusions (Palomares, Ogbonna, Landau, & Egeth, 2009). They also perform the same or better than MA controls in biological motion perception (Jordan et al., 2002) and motion coherence tasks (Reiss, Hoffman, & Landau, 2005), both of which require judgments about the direction of motion of groups of dots. Moreover, beyond these tasks, which examine the perception of spatial layouts and configurations of multiple objects, WS individuals also show performance

no different from MA controls on other more broadly defined “visual-spatial” abilities that may be involved in our task, including object recognition from canonical and unusual perspectives (Landau, Hoffman, & Kurz, 2006), and orientation perception (Dilks et al., 2008). This large body of data suggests that the failure to predict the direction in which the tower will fall is unlikely to be accounted for by inaccurate perception of the tower configurations.

Another possible alternative account of our findings is that there is a visual-spatial deficit in reasoning, more generally, that compromises participants’ decisions about which way the tower should fall. Indeed, the hallmark of individuals with WS is a failure in visual-spatial construction tasks, which require that one generate predictions about how individual objects can be assembled to create a specific configuration, and then carry these predictions out by assembling the configuration. It is possible that such predictive reasoning about spatial configurations overlaps in some way with the predictive reasoning about the direction in which a tower will fall, but the two kinds of predictive reasoning tap into quite distinct content domains. The first is about a predicted spatial configuration; the second is about the force-dynamic properties of the objects themselves and in combination (e.g., the mass of the blocks and their distribution across the tower) and the external forces (e.g., gravity) that act on these objects (Battaglia et al., 2013)—properties that are fundamental to intuitive physical reasoning, but not critical to understanding how objects combine to create new spatial configurations. In short, visual-spatial reasoning may have in common with physical reasoning an ability to make predictions, but the content of the two domains is quite different. Indeed, a recent fMRI study has identified brain regions that preferentially respond not only to the task tested here, but also to another intuitive physics task (i.e., requiring participants to predict the spatial path of dots whose motion implies physical interactions) compared to a task that involved visual-spatial reasoning outside the domain of intuitive physics (i.e., requiring participants to predict the spatial path of these same dots whose motion implies social interactions) (Fischer et al., 2016). Taken together, these data suggest that our intuitive physics task does in fact recruit intuitive physical reasoning, and that it is distinct from general visual-spatial reasoning.

The idea that intuitive physics is distinct from visual-spatial reasoning raises new questions: First, how does the intuitive physical reasoning system intersect with other cognitive systems, including those that support predictive functions about spatial arrays? Is intuitive physics distinct from the ability to carry out visual-spatial constructive functions, or is there functional overlap between the two systems? Second, what is the precise nature of the hypothesized intuitive physics deficit in WS? Are WS individuals impaired on all aspects of intuitive physics, or just some (e.g., are they impaired at understanding physical properties of objects themselves, the external forces acting on objects, or both)? Future work addressing both of these questions will shed light on the precise nature of the intuitive physical reasoning system. In particular, individuals with WS should be tested on a wider array of physical reasoning tasks (and more closely matched non-physical tasks) (e.g., Baillargeon, 1998; Fischer et al., 2016; Hamrick, Battaglia, Griffiths, & Tenenbaum, 2016; Heider & Simmel, 1944; Kotovsky & Baillargeon, 2000; Leslie & Keeble, 1987; Luo, Kaufman, & Baillargeon, 2009; Michotte, 1963; Oakes, 1994; Smith & Vul, 2013), to identify the specificity of intuitive physics deficit, and how it might relate to other deficits involving reasoning about spatial configurations.

Finally, the present study may shed light on the development of the WS cognitive phenotype. In particular, our finding that WS adults performed similar to typically developing 4 year olds partially supports the hypothesis that the WS cognitive profile arises

from developmental arrest of later developing cognitive systems found in typical development (Landau & Ferrara, 2013). However, the present study did not find evidence for the further prediction of this hypothesis that intuitive physics is typically later to develop than intuitive psychology, at least in the ages tested here. Thus, future work will need to test children younger than 4 years old, as well as children with WS, in order to more fully test the hypothesis that intuitive physics and intuitive psychology develop differentially across typical development, and to directly assess how the typical developmental trajectories of intuitive physics and intuitive psychology relate to the development of those abilities in WS, resulting in the adult WS profile observed here (i.e., impaired intuitive physics, relatively spared intuitive psychology). Moreover, this work could begin to shed light on the particular mechanisms that drive the development of the intuitive physics impairment in WS. For example, WS individuals may simply be less inclined toward the physical world, resulting in insufficient learning experiences. This possibility is consistent with the developmental literature showing a crucial role of experience in shaping intuitive physical reasoning (Baillargeon, 1998; Baillargeon & Carey, 2012). Another possibility is that genetic factors place a limit on the ability of the system to learn about the physical world beyond what is typically achieved around 4 years of age. Consistent with this possibility, studies of WS individuals with atypical deletions suggest that particular genes play a role in visual-spatial (e.g., LIMK-1) versus social aspects (e.g., GTF2I) of the disorder (Dai et al., 2009; Frangiskakis et al., 1996; Sakurai et al., 2011).

In conclusion, here we found that intuitive physics is disproportionately impaired relative to intuitive psychology in the case of WS. This dissociation provides a striking complement to previous work showing that individuals with ASD are impaired in intuitive psychology, but not intuitive physics—an effective double dissociation. Taken together, these results indicate that intuitive physics and intuitive psychology are not supported by a single, more general system for causal reasoning, but rather constitute independent cognitive domains.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at <http://dx.doi.org/10.1016/j.cognition.2017.06.027>.

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