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Modulation of Social Influence by Methylphenidate

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The ability to infer value from the reactions of other people is a common and essential ability with a poorly understood neurobiology. Commonly, social learning matches one's values and behavior to what is perceived as normal for one's social group. This is known as conformity. Conformity of value correlates with neural activity shared by cognitions that depend on optimum catecholamine levels, but catecholamine involvement in conformity has not been tested empirically. Methylphenidate (MPH) is an indirect dopamine and noradrenalin agonist, commonly used for the treatment of attention-deficit hyperactivity disorder for which it reduces undesirable behavior as evaluated by peers and authority figures, indicative of increased conformity. We hypothesized that MPH might increase conformity of value. In all, 38 healthy adult females received either a single oral 20 mg dose of MPH or placebo (PL). Each subject rated 153 faces for trustworthiness followed immediately by the face's mean rating from a group of peers. After 30 min and a 2-back continuous-performance working-memory task, subjects were unexpectedly asked to rate all the faces again. Both the groups tended to change their ratings towards the social norm. The MPH group exhibited twice the conformity effect of the PL group following moderate social conflict, but this did not occur following large conflicts. This suggests that MPH might enhance signals that would otherwise be too weak to evoke conformity. MPH did not affect 2-back performance. We provide a new working hypothesis of a neurocognitive mechanism by which MPH reduces socially disruptive behavior and provides novel evidence of catecholamine mediation of social learning.
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INTRODUCTION

From food to politics, our choices and behaviors are guided by the values we associate with the available options. The ability to infer the value of an option from opinions expressed by others is an essential skill. This skill enables us to learn quickly about options without the costs that accompany trial and error. It allows values to be taught intentionally and passed from one generation to the next. It even enables us to build representations of other people's desires so that we can cooperate effectively and enhance our own reputations. Remarkably little is known about how social learning occurs, despite its common occurrence across species (Galef and Laland, 2005). This study investigates the role of catecholamines in the social learning process. The results provide new insight into pharmacological treatments of social learning deficits and increase our understanding of the social impact of certain pharmacological events.

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When social learning matches one's values and behavior to what is perceived as normal for one's social group, it is conformity. Conformity can be motivated by gains of reputation, gains of knowledge, or both (Cialdini and Goldstein, 2004; Deutch and Gerard, 1955). Either can lead to more positive and fewer negative future outcomes (Fehr and Fischbacher, 2004; Turner, 1991). Conformity of value can therefore involve learning about the value of an object or event, as well as the value of agreement with others (Campbell-Meiklejohn *et al*, 2010). Correspondingly, studies have consistently reported that cognitive components of conformity can be tracked in the activity of brain regions known to mediate reinforcement learning. These include responses to social agreement (Campbell-Meiklejohn *et al*, 2010), conformity-inducing conflict (Berns *et al*, 2010; Campbell-Meiklejohn *et al*, 2010; Klucharev *et al*, 2009), changes of reputation (Izuma *et al*, 2008; Zink *et al*, 2008), and socially induced changes of object value (Campbell-Meiklejohn *et al*, 2010; Mason *et al*, 2009; Zaki *et al*, 2011). In nonsocial domains, task performance related to the same fronto-striatal circuitry is known to be sensitive to levels of catecholamine activity (Berridge, 2007; Clatworthy *et al*, 2009; Cools *et al*, 2001; Del Campo *et al*, 2011; Robbins and Arnsten, 2009), but catecholamine mediation of conformity of value has not yet been established.

Methylphenidate (MPH) is an indirect catecholamine agonist that increases extracellular dopamine and noradrenalin levels in the brain (Berridge *et al*, 2006; Volkow *et al*, 2001) with consequences for learning and other cognitions. With respect to value, MPH can enhance phasic dopamine responses to external stimuli and associated interest in rewards and tasks (Volkow *et al*, 2002, 2004), modulate flexible adaptation of stimulus–reinforcement association (Clatworthy *et al*, 2009), and alter reinforcement-associated synaptic plasticity and behavior (Tye *et al*, 2010). In other domains, it can alter cognitive performance that is dependent on optimum catecholamine levels including working memory, vigilance, and response inhibition (Arnsten, 2011; Del Campo *et al*, 2011; Swanson *et al*, 2011). MPH could therefore affect conformity to the extent that it depends on any of these processes.

Clinically, MPH is a very common treatment of attention deficit hyperactivity disorder (ADHD) (Wilens, 2008). It is also increasingly abused as a nonprescribed 'cognitive enhancer' (Smith and Farah, 2011). For ADHD patients characterized by inappropriate social behavior as evaluated by authority figures and peers, MPH and other stimulants tend to improve social performance (Gadow *et al*, 1995; Hinshaw *et al*, 1989; Klein *et al*, 1997; Pelham *et al*, 1985; Spencer *et al*, 2005; Sprague and Sleater 1977; Whalen *et al*, 1989). This effect may occur, in part, from increased conformity.

As evident from an infant observing a mother's reaction to a stranger (Feinman *et al*, 1992), a particularly common and important socially learned value is trust. Trust is the value of a social interaction based on the perceived likelihood that the other party will act in one's best interests. Trustworthiness judgments of faces are good approximations of the overall valence (positive/negative) of face stimuli and reflective of approach/avoidance decisions in the absence of clear emotional cues of the other person's intentions (Todorov, 2008).

Given the overlap of neural activities supporting conformity and nonsocial catecholamine-mediated cognition, we anticipated that MPH might affect conformity of value. Because MPH enhances reinforcement saliency in healthy adults and makes behavior of patients more acceptable to one's peers and authority figures, we anticipated that the effect would be to increase conformity. We adapted a task shown to be sensitive susceptibility to social influence (Klucharev *et al*, 2009, 2011; Zaki *et al*, 2011) to test for the effect of MPH on conformity of trustworthiness-ratings of faces.

MATERIALS AND METHODS

Recruitment and Screening

The ethics committee of Central Jutland Region, Denmark, reviewed the methods and approved this study. Subjects were recruited with posters and newspaper advertisements. Prospective subjects were given a physical examination by a physician and screened according to certain criteria before being accepted onto the study. To be accepted onto the study, subjects had to be nonsmokers, female, between the ages of 18 and 35, free of current DSM-IV illness, free of history of major depression, free of psychotropic drugs (except for oral contraception) for 3 months, free of head injury or stroke, and free of any illness or medication associated with adverse interactions with an acute dose of MPH. Only women were used in this study because the faces of the experiment's task were exclusively of women and we wished to avoid confounds of cross-gender effects on trustworthiness ratings.

Subjects: Demographics, State, and Trait Measures

Thirty-eight healthy women were matched for age (M 23, SD 2.7), years of education (M 13.8, SD 1.8), performance intelligence (WAIS-III Matrix Reasoning, scaled M 11.53, SD 1.7), and verbal intelligence (WAIS-III Vocabulary, scaled M 12.7, SD 1.7) (Wechsler, 2005), and randomly assigned to one of the two drug groups by an independent third party. Before the test day, trait measures of anxiety (Spielberger, 1970), social anxiety (Liebowitz, 1987), self-monitoring (Snyder and Gangestad, 1986), and mood (Watson *et al*, 1988) were recorded for each subject. State measures of anxiety (Spielberger, 1970), mood (Watson *et al*, 1988), nausea, and headache were recorded immediately before receiving the drug or placebo (PL) and again just prior to the testing.

Procedure

In a double-blind procedure, one group received a single 20 mg oral dose of MPH, whereas the other received a PL. Subjects were tested within the first 12 days of their menstrual cycle and were asked to refrain from caffeine 24 h prior to the study. One hour after receiving the drug, subjects performed the first session of the conformity task. This took about 12 min. Next, subjects performed a 2-back continuous-performance working-memory task (Owen *et al*, 2005) and an unrelated gambling task (Campbell-Meiklejohn *et al*, 2011). At 30 min after the initial ratings, subjects were surprised with the second session of the conformity task. Subjects did not know about the second session until this point. The second session took approximately 8 min. Both the cognitive tasks were presented to subjects on a computer using Presentation v. 14 (Neurobehavioral Systems).

Conformity Task

The task (Figure 1) was similar to that described previously (Klucharev *et al*, 2009, 2011; Zaki *et al*, 2011). Subjects rated 153 female faces with moderate smile and attractiveness on a scale from 1 (not at all) to 8 (very), for how 'trustworthy' they believed the owner of the face to be. The faces were presented in a random order. After rating each face, subjects were told the average rating of that face by other subjects performing the task at other European universities. This group rating is the 'social norm.' The mean initial rating of the faces by subjects was 4.8 ± 0.4 (SD). Subtraction of subject ratings from the social norm resulted in our independent variable of 'social conflict' for each face. To enable comparisons with neuroimaging studies that used similar tasks (Klucharev *et al*, 2009, 2011; Zaki *et al*, 2011), we used the same five social conflict conditions as those studies. Subjects could be in 'no conflict' (NC) (within 1, including zero), moderate social conflict (-2, $+2$), or high

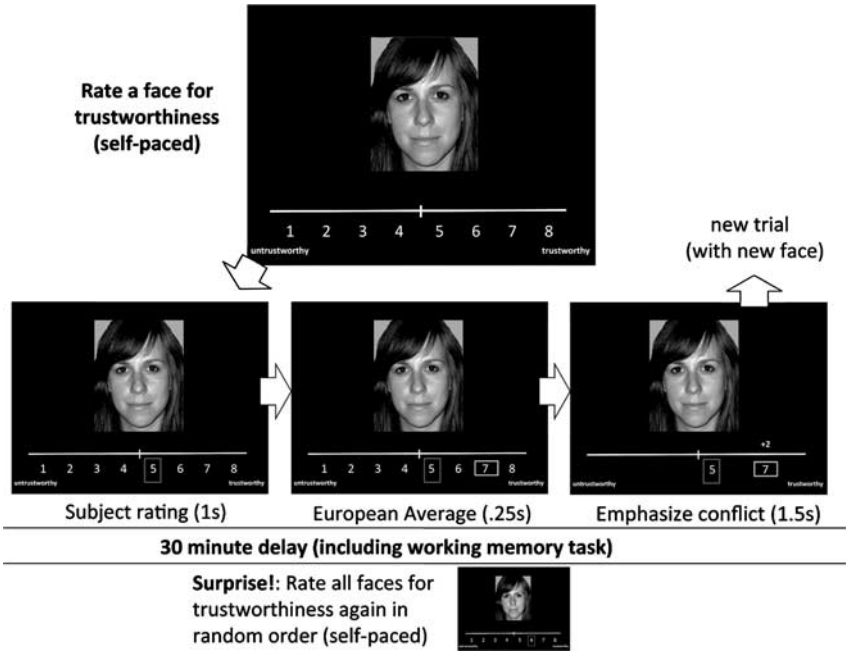

Figure 1 Conformity Task. Subjects rated 153 faces, one by one, for their expected trustworthiness on a scale from 1 to 8, indicated by pressing the corresponding number on a keyboard. The choice was highlighted by a green vertical rectangle. After rating each face, subjects learned the 'social norm' rating of that face, which subjects were told was the average rating from four identical studies in European universities. The social norm rating was highlighted by a horizontal blue rectangle so that overlap with the subject's response could be observed. Social conflict with the norm could be 'no conflict', moderate (± 2), or high (± 3). Subjects were told that low conflict (± 1) would be displayed as 'no conflict'. Unexpectedly, subjects rated the faces again after 30 min, in a random order, without social feedback. Display was presented to subjects in color.

social conflict (-3, $+3$) with the social norm. Social conflict was negative if the social norm had a lower rating than the subject, and positive if the social norm was higher. Subjects were informed that the visual feedback for -1, 0, and $+1$ social conflict would be identical.

Unbeknownst to subjects, social conflict was not real. It was anchored to the subject's rating to ensure that enough events occurred in each social conflict condition to make a reliable estimate of conformity. This provided approximately 22 faces with a social conflict of -3, 28 with -2, 52 with NC, 30 with $+2$, and 20 with $+3$. Thirty-seven subjects expressed no doubts about the study's story authenticity, and one reported only mild doubt when debriefed at the end of the experiment.

The surprise second session, 30 min later, was a rerating of all the faces for trustworthiness on the same scale, in random order, without social norm feedback.

Dependent Measures of Conformity

We recorded the change of trustworthiness rating from before to after learning the social norm rating of each face (between sessions).

C_{opin} is the mean change of face rating. We calculated C_{opin} for each of the five social conflict conditions (-3, -2, NC, $+2$, and $+3$). C_{opin} was positive if the subject's second rating was higher, on average, than their initial rating and negative if the second rating was lower.

C_{twrd} is the mean change of face rating towards the social norm. C_{twrd} was positive if the subject's rating changed, on average, towards the social norm and negative if it changed away. We calculated C_{twrd} values for all social conflict levels (-3, -2, $+2$, and $+3$) and conflict conditions collapsed by magnitude (± 2, ± 3).

Reaction time and probability of conformity were also recorded.

2-Back

Subjects performed the 2-back task at the time of screening (baseline) and between the sessions of the conformity task. The 2-back is a continuous performance measure of sustained attention and working memory. Subjects are asked to press a button when the displayed letter (one out of five possible) matches the letter displayed 2 letters earlier in a continuous sequence. These letters were targets. Each letter was displayed for 2 s on a computer display in a series of 152 trials. The letters were presented in a random order. Correct indication is a 'hit,' missing an indication is a 'miss', and incorrect indication is a 'false alarm.' Changes of hits, misses, and false alarms before and after drug or PL treatment were the dependent measures of this study.

Statistical Analysis

All tests were performed with SPSS 19.0 (IBM). Normality of the dependent variables was determined by a statistical threshold of kurtosis and skewness statistics ($Z < 1.96$). Mann–Whitney *U*-tests were used in place of independent *t*-tests when normality assumptions were violated. Where assumptions of sphericity were deemed violated by Mauchley's test in repeated-measures analysis of variance

(ANOVA), degrees of freedom were corrected by Greenhouse–Geisser estimates.

Demographic, states, and traits. Independent sample *t*-tests were used to test for any between-group differences on demographic, state, or trait measures.

Conformity. To test if C_{opin} was related to by social conflict, drug treatment, or an interaction between the two, we used a mixed design ANOVA. The within-subject factor was social conflict (five levels: −3, −2, NC, +2, and +3) and the between-subject factor was drug group (MPH *vs* PL). In case of ceiling effects, we performed a similar analysis for C_{opin} in the range of moderate conflict (only three within-subject levels: −2, NC, and +2).

To compare if the conformity differed between positive and negative social conflict, we used paired *t*-tests of C_{twrd} following +2 *vs* −2 and +3 *vs* −3. Because no differences were observed ($Ps > 0.33$), we used the more reliable (more trials) C_{twrd} values of ±2 and ±3 for subsequent analysis. A single outlier with a very large C_{twrd} value following moderate (±2) social conflict was changed to the ±2 C_{twrd} value (plus 0.01) of the participant with the next highest value to ensure homogeneity of variance between groups, as recommended (Field, 2009). A mixed design ANOVA was performed on C_{twrd} with social conflict (±2, ±3) as a within-subject factor and drug group as a between-subject factor. Independent sample *t*-tests were then done to further investigate for differences of C_{twrd} between drug groups following moderate ($\leqslant \pm 2$), and separately, following high (±3) social conflict.

To test if conformity was more frequent following high (*vs* moderate) social conflict, a repeated-measures ANOVA was used to compare the mean probability of a change towards the social norm between the two conditions across all subjects. To ensure that effects did not emerge from group differences of original ratings or tendencies to change opinions, independent sample *t*-tests were used to compare mean initial trustworthiness ratings and C_{opin} on NC trials between drug groups. Reaction times were tested between groups by independent sample *t*-tests in each social conflict condition for both sessions.

Effects on fatigue. To check that group differences of conformity were not due to prevention of fatigue by MPH, correlation coefficients were calculated for trial number × reaction time and for trial number × C_{twrd} following moderate social conflict for each subject. The resulting correlation coefficients were tested for differences between drug groups by independent sample *t*-tests.

2-back. The effect of drug on 2-back performance was tested as (a) a main effect of drug group on each dependent measure during post-treatment performance by independent sample *t*-test; and (b) the interaction of the effects of drug and session on each dependent measure from a mixed model repeated-measures ANOVA with session as a within-subject factor and drug group as a between-subject factor. Repeated-measures ANOVAs were used to confirm equal number of targets in both sessions, in both groups. Independent sample *t*-tests confirmed equal baseline performance in each group.

RESULTS

Conformity behavioral measures are summarized in Table 1. N-back behavioral measures are summarized in Table 2. Trait and state measures are summarized in Supplementary Tables S1 and S2 (see Supplementary Information).

Demographic State and Trait Measures

MPH subjects increased positive mood more than PL subjects after treatment ($t(36) = -3.2$, $P < 0.01$), but positive mood did not significantly differ between-groups at the time of testing and the change in mood did not correlate with the measures of conformity ($Ps > 0.2$). No other demographic, trait, or state measure differed between drug groups or correlated with conformity.

Conformity Effects

We observed a main effect of social conflict (five levels: −3, −2, NC, +2, and +3) on C_{opin} ($F(4, 144) = 87.95$, $P < 0.001$). This confirmed that a relationship between social conflict and changes of opinion on the conformity task.

No overall interaction was observed between the effects of social conflict and drug group on C_{opin} across the full range of conflicts (five levels: −3, −2, NC, +2, and +3) ($P > 0.18$). Within the range of moderate social conflict (three levels: −2, NC, and +2), however, a significant interaction between the effects of social conflict and drug group on C_{opin} was observed ($F(1.58, 56.9) = 3.43$, $P < 0.05$) (Figure 2a). This range still contained a strong main effect of social conflict on C_{opin} ($F(1.58, 56.9) = 35$, $P < 0.001$). This established an effect of drug on conformity within the range of moderate social conflict.

We observed a main effect of social conflict (moderate (±2) *vs* high (±3)) on C_{twrd} ($F(1, 36) = 62.35$, $P < 0.001$). Subjects conformed more if the conflict was high. In the same analysis, we observed an interaction between the

Table 1 Conformity Measures

Measure	Drug group			
	PL		MPH	
	Mean	SE	Mean	SE
Mean reaction time (ms), first rating	2995.27	164.68	3191.05	224.73
Mean reaction time (ms), second rating	2218.87	169.14	2536.99	200.34
Mean trustworthiness rating, first rating	4.88	0.11	4.74	0.12
Mean trustworthiness rating, second rating	4.93	0.15	4.77	0.14
C_{opin}, group is 3 lower	−0.51	0.12	−0.61	0.11
C_{opin}, group is 2 lower	−0.11	0.10	−0.31	0.14
C_{opin}, no conflict	0.00	0.11	0.04	0.08
C_{opin}, group is 2 higher	0.26	0.09	0.40	0.09
C_{opin}, group is 3 higher	0.74	0.11	0.62	0.11
C_{twrd}, group rating ±2 conflict	0.19	0.04	0.37	0.07
C_{twrd}, group rating ±3 conflict	0.61	0.06	0.59	0.07
Conformity probability, ±2 conflict	0.43	0.02	0.45	0.02
Conformity probability, ±3 conflict	0.50	0.01	0.50	0.02

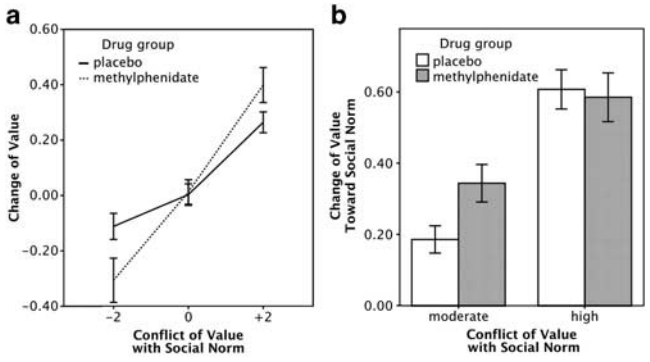

Figure 2 Methylphenidate Effect on Conformity. Subjects treated with methylphenidate conformed more following moderate social conflict. (a) Change of value (C_{opin}) for moderate social conflict magnitudes of −2, NC, and 2. Error bars reflect one within-subject SE. (b) Change of value towards social norm (C_{twrd}) for moderate (±2) and high (±3) social conflict conditions. Error bars reflect one between-subject SE.

Table 2 N-Back Dependent Measures

Measure	Drug group	Session 1 = pre drug, 2 = post drug	Mean	SE
Hits	Placebo	1	27.579	1.348
		2	33.632	1.433
	Methylphenidate	1	29.789	1.348
		2	33.053	1.433
Misses	Placebo	1	10.053	1.243
		2	6.421	0.878
	Methylphenidate	1	7.895	1.243
		2	5.579	0.878
False alarms	Placebo	1	7.632	1.263
		2	6.316	1.235
	Methylphenidate	1	6.789	1.263
		2	4.526	1.235

effects of social conflict and drug group on C_{twrd} ($F(1, 36) = 4.67$), $P < 0.039$). Independent sample *t*-tests established that this interaction was due to MPH having no effect on C_{twrd} after high conflict ($P > 0.8$) but evoking twice the C_{twrd} of PL after moderate conflict ($t(36) = 2.4$, $P < 0.022$) (Figure 2b).

Initial trustworthiness ratings and experienced social conflict were similar between drug groups ($Ps > 0.38$). In the NC condition, C_{opin} did not differ between drug groups, which indicated that there was no group difference of a general tendency to change opinion between sessions. We did not observe differences of reaction time between drug groups in any social conflict condition ($Ps > 0.16$). High (*vs* moderate) conflict generated a greater mean probability of conformity than moderate conflict across all subjects ($F(1, 37) = 18.6$, $P < 0.001$).

Fatigue

Correlations between trial number × reaction time and trial number × C_{twrd} following moderate conflict did not differ between MPH and PL groups ($Ps > 0.25$). Conformity results were therefore unlikely to result from MPH effects on fatigue.

2-Back

Drug groups did not differ on any 2-back performance measure before or after treatment ($Ps > 0.25$) (Table 2). Subjects generally improved on each dependent measure of the 2-back task between pre and post treatment (hits: $F(1, 36) = 14.9$, $P < 0.001$; misses $F(1, 36) = 12.6$, $P < 0.001$; and false alarms: $F(1, 36) = 5.4$, $P < 0.03$), but groups showed similar improvements ($Ps > 0.25$). Targets were presented equally often in both groups ($P > 0.5$) and sessions ($P > 0.2$). The effect of MPH on conformity was therefore unlikely to result from a general effect on working memory or sustained attention.

DISCUSSION

The conformity task elicited conformity in both groups as predicted by previous studies using a similar task (Klucharev *et al*, 2009, 2011; Zaki *et al*, 2011). The tendency to increase magnitude and probability of conformity reflects the findings of early conformity research (Fisher and Lubin, 1958; Goldberg, 1954; Hovland and Pritzker, 1957; Zimbardo, 1960). Subjects who received MPH exhibited twice the conformity of subjects receiving a PL after moderate social conflict without observed effects on working memory, sustained attention, or fatigue. This provides initial pharmacological evidence that catecholamine systems could underlie conformity to social norms found in previous neuroimaging studies (Campbell-Meiklejohn *et al*, 2010; Klucharev *et al*, 2009). We found no evidence that the conformity results reflected MPH effects on sustained attention, working memory, or fatigue.

A mechanism of MPH effects on social influence is suggested by prior research. A low oral dose of MPH has been shown to increase the levels of extracellular dopamine in the striatum in response to appetitive stimuli, indicative of stimulus-driven phasic dopamine release (Volkow *et al*, 2001, 2002, 2004; Wightman and Robinson, 2002). This increase is accompanied by increases of stimuli desirability, interest, and motivation during cognitive tasks (Volkow *et al*, 2002, 2004). Volkow *et al* (2005) have proposed that MPH amplifies dopaminergic responses to appetitive stimuli that would otherwise be of insufficient strength to establish enough salience to interest the subject. For the current results, we suggest that MPH may amplify dopamine responses to cues for moderate gains of conformity-based rewards that would otherwise lack the necessary strength or duration to reliably change a face rating. In contrast, relatively larger conflicts may generate signals of sufficient strength to reliably induce conformity without enhancement by MPH. Such a hypothesis assumes that the incentive salience of conformity increases with the size of social conflict and that a threshold of salience needs to be met to induce conformity. Our finding that conformity was also more frequent when conflict was high, as compared with moderate, supports this case. Further support for the incentive of conformity is gained from neuroimaging

findings that agreement with others and gains of reputation evoke similar reward activity in the striatum to that of nonsocial rewards (Campbell-Meiklejohn *et al*, 2010; Izuma *et al*, 2008; Zink *et al*, 2008). The hypothesis also assumes that the magnitude of a cued incentive is carried by phasic dopamine signals, which has been shown previously (Tobler *et al*, 2005). In future work, modulation of phasic dopamine responses by factors already known to increase the incentive of conformity, such as group size and consensus among the group (Asch, 1951), would further support this interpretation.

Subjects did not differ on a 2-back task reflecting working memory and sustained attention performance. This reduces the likelihood that group differences of conformity arose from improvement on these measures. Null effects of MPH on the 2-back performance have been found previously (Mattay *et al*, 2000). In contrast, previous studies (Elliott *et al*, 1997; Mehta *et al*, 2000) have found that MPH can affect spatial working memory in healthy volunteers. One possible explanation for the discrepancy with our results is that the two tasks have different cognitive requirements (Smith and Farah, 2011). Another potential explanation is experience. Elliott *et al* (1997) found that MPH could improve spatial working-memory performance on the first exposure to the task but impair it on the second. Our subjects performed the task before and after drug administration so that we could account for baseline cognitive ability. It is possible that one might find a different result if MPH-treated subjects only encountered the 2-back once, but such a study would not account for baseline performance.

While the suggested mechanism centres on the activity of the basal ganglia and dopamine, effects of MPH on prefrontal cortex and noradrenalin should not be discounted (Arnsten, 2011). Microdialysis studies in rats have shown that MPH has pronounced effects on catecholamine levels of the prefrontal cortex (Berridge *et al*, 2006). In humans, MPH has been shown to bind to noradrenalin transporters (Hannestad *et al*, 2010), but this is not yet demonstrated in the frontal cortex because of limitations of positron emission tomography. Prefrontal cognitions affected by MPH include working memory (Elliott *et al*, 1997; Mehta *et al*, 2000) and response inhibition (Nandam *et al*, 2011). Studies also show that noradrenalin may mediate important functions of working memory, attentional set shifting, and response inhibition (Arnsten, 2011). Such cognitions could theoretically support conformity task performance but the precise contribution is not clear in the absence of MPH effects on the 2-back task and use of a wider range of control tasks. Future studies can build on this study work by comparing the effects of MPH with the effects of atomoxetine (a prefrontal specific catecholamine agonist) and observe interactions with specific dopamine and noradrenaline antagonists to isolate the neural structures and specific neurotransmitters involved. Given the distribution of cortical and striatal systems involved in social conformity (Berns *et al*, 2010; Campbell-Meiklejohn *et al*, 2010; Klucharev *et al*, 2009), we expect that, as for nonsocial learning (Kehagia *et al*, 2010), conformity involves a network of brain regions, multiple cognitions, and interactions between multiple neurotransmitter systems (Boureau and Dayan, 2011; Cools *et al*, 2011).

Although we observe a main effect across all subjects, MPH mediation of social learning may be dose-dependent and vary with individual differences of baseline tendency and baseline catecholamine activity (Clatworthy *et al*, 2009; Del Campo *et al*, 2011; Volkow *et al*, 2005). Effects for healthy adults may not be the same as for individuals with catecholamine deficits. Moreover, as this study demonstrates, stimulants may improve performance on some tasks but impair or have no effect on others, consistent with data suggesting inverted U-shaped relationships between levels of catecholamines and performance can vary between tasks (Arnsten, 2009; Clatworthy *et al*, 2009; Cools *et al*, 2001; Robbins and Arnsten, 2009; Yerkes and Dodson, 1908). Future work should explore the effects of different doses of MPH, baseline conformity tendency, and baseline catecholamine activity on conformity behavior.

One might argue that the effects we observe may not be 'social' because subjects performed the task on a computer. Performing a computer-based task will likely have different nuances to a true social interaction, and field studies are needed to determine if results deriving from this laboratory experiment extend to real world social interactions. All subjects, however, did report belief in the background story of the experiment, which includes a belief in the social nature of the task. Moreover, changes of value towards feedback ratings tend to be much higher in social versions of this task compared with those when subjects are told a computer-provided feedback, as demonstrated by Klucharev *et al.* (2009). The effects reported here are well within the range of the social version.

Given the length of time between ratings, the large number of faces, the rapid pace, the distracter tasks, the randomization of face order between sessions, and the fact that subjects did not expect to rerate the faces, it was very unlikely that subjects explicitly remembered their original ratings or associated social conflict at the time of the second rating. Given that changes of value are detectable in reinforcement circuitry a second after the social conflict (Campbell-Meiklejohn *et al*, 2010), we believe that changes of value proably occur during the first session and without a necessity to remember the conflict at the second session. Still, we do not completely rule out that a few faces and ratings could have been recognized at the times of the second rating, and explicit processes and recognition memory may factor slightly into the results.

The etiology of social deficits in disorders such as ADHD and reasons for therapeutic effectiveness of MPH to alleviate these deficits is not established by these findings in healthy adults. However, it is plausible that stimulant-induced increases of conformity could contribute to MPH effects on social behavior. An MPH-induced increase in the incentive of conformity, for example, would be consistent with theories and findings that patients with ADHD have reinforcement learning deficits that can be alleviated by stimulant therapy (Frank *et al*, 2007; Haenlein and Caul, 1987; Luman *et al*, 2010; Volkow *et al*, 2005; Wilkison *et al*, 1995), enhanced responses to raised incentives (Andreou *et al*, 2007; Kohls *et al*, 2009; Luman *et al*, 2005), deficient psychophysical responding to affective stimuli that can be restored by stimulant medication (Conzelmann *et al*, 2011; Groen *et al*, 2009), and reduced hemodynamic responses to reward anticipation in the striatum (Plichta *et al*, 2009;

Stark *et al*, 2011; Strohle *et al*, 2008). We therefore propose a new working hypothesis that MPH may improve social behavior and acceptance by peers in ADHD patients, in part, by increasing catecholamine-mediated conformity. The specificity of MPH effects on conformity following moderate conflict may translate to increases of patient learning from subtle social cues that would otherwise have little effect on values and behavior. When values become similar to values of the group, resulting behavior is more likely to be favorably viewed by group members and authority figures. A better understanding of reward deficits of ADHD (Luman *et al*, 2010) may informs our understanding of associated social deficits and their treatment.

Finally although we are beginning to shed light on 'how' subjects change our values, future studies still need to establish 'why' subjects conform more on MPH. Subjects may have altered their opinion because the social norm is considered a better indicator of value than their own deduction. Alternatively, subjects may have believed that holding opinions similar to the social norm will bring more associated rewards and less punishments from others in society (Cialdini and Goldstein, 2004; Fehr and Fischbacher, 2004). Reasons for conformity will also vary from person to person. It is difficult to distinguish reasons for conformity in behavior or neuroimaging of the reward system because different incentives can elicit similar responses. Creative experimental techniques are required to empirically tease the motivations apart.

Summary

We have presented novel evidence of catecholamine mediation in social learning. This is a critical step toward understanding the neurobiology of this essential social cognition. The results highlight a potential overlap in pharmacology of nonsocial and social learning worthy of future study in the lab and real world situations. Like the incentive value of appetitive stimuli, the incentive value of conformity may be enhanced by stimulant medication. The findings also provide a new working hypothesis of a neurocognitive mechanism by which MPH might help to reduce disruptive behavior as judged by peers and authority figures, through enhancement of conformity-related cognition.

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DISCLOSURE

The authors declare no conflict of interest.

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