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The Influence of Schizotypal Traits on the Preference for High Instrumental Divergence

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Abstract

A large literature has demonstrated an abnormal sense of agency (SOA) in schizophrenic individuals. One limitation of such studies is that they focus exclusively on cognitive or perceptual judgments, thus failing to address affective aspects of SOA. In our recent work, we have used *instrumental divergence* – the distance between outcome probability distributions associated with available actions – as a formal measure of agency, demonstrating an influence of this novel decision variable on behavioral choice preferences and associated neural computations in neurotypical adults. Here, we show that the preference for high instrumental divergence (i.e., for high-agency environments) is significantly modulated by individual differences in positive and negative schizotypy dimensions. Implications for future assessments of clinical populations are discussed.

Keywords: Instrumental divergence; Agency; Schizotypy, Utility

Introduction

The ability to exert voluntary control over one's environment is a central feature of adaptive decision-making and a hallmark of intelligent systems. It is not surprising, then, that a range of affective and cognitive disorders are characterized by an abnormal *sense of agency* (SOA)[1-8]. Schizophrenic individuals, in particular, differ from healthy controls in their self vs. external attributions of events, as well as in the degree of intentional binding – a perceived compression of the time interval between an action and its consequence[1-5]. While operational definitions of agency and volition differ across such findings, they share some fundamental limitations: First, they often conflate the estimation or representation of an action-outcome contingency with the subjective experience of volitional control. Second, they focus exclusively on cognitive or perceptual judgments, thus failing to address affective aspects of SOA. In our recent work, we have used *instrumental divergence* – the distance between outcome probability distributions associated with available actions – as a formal measure of agency, demonstrating an influence of this novel decision variable on behavioral choice preferences and associated neural computations in neurotypical adults[9,10]. Here, we assess the relationship between effects of instrumental divergence and individual differences in schizotypal traits.

To illustrate the significance of instrumental divergence, consider the two scenarios represented in Figures 1A and 1B respectively, each of which entails two available actions, A1 and A2, and the transition probabilities of each action into three potential outcome states, O1, O2 and O3. Note that, if the utilities of O1 and O3 are the same, then according to conventional accounts of economic choice – from rational choice theory to prospect theory and reinforcement learning theory – all actions depicted in Figure 1 have the same *expected utility*: Consequently, there should be no preference for one scenario over the other. And yet, if one considers the dynamic nature of subjective outcome utilities, the two scenarios clearly differ. For example, imagine that O1 and O3 represent food and water respectively, and that, at the point of choosing between the two scenarios, you are as hungry as you are thirsty, rendering both outcomes equally attractive. However, after a large meal without a drop to drink, your desire for O3 would likely be greater than that for O1; conversely, having thoroughly quenched your thirst, you would prefer O1. Unlike the scenario illustrated in Figure 1A, the high instrumental divergence in Figure 1B allows you to produce the currently desired outcome as preferences change, by switching between actions: Thus, as instrumental divergence increases, so does the degree of agency and, consequently, the opportunity to maximize long-term reward.

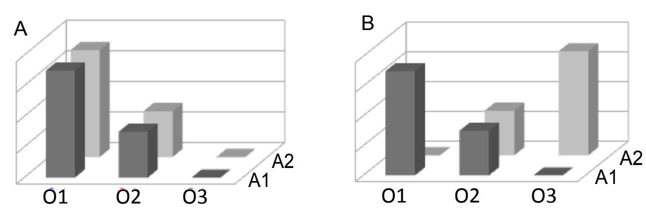

Figure 1: Probability distributions over three potential outcomes (O1, O2 & O3) for two available actions (A1 & A2) across which instrumental divergence is either zero (1A) or high (1B).

In previous work, we have demonstrated a clear preference for the scenario depicted in Figure 1B over that in Figure 1A, and have dissociated this influence of instrumental divergence from that of other motivational and information theoretic factors, including expected utility, outcome entropy, outcome diversity and free vs. forced choice [9]. We have also identified a neural signal scaling with instrumental divergence in the supramarginal gyrus of the inferior parietal lobule [10], a brain region known to differ volumetrically across schizophrenic and neurotypical individuals [11-15]. In the current study, to clarify the nature of aberrant SOA in schizophrenia, particularly with respect to its role in motivated behavior, we relate the behavioral preference for high instrumental divergence to dimensions of schizotypy.

Methods

Participants Sixty undergraduates at the University of California, Irvine (47 females; mean age = 21.3 ± 2.7) participated in the study for course credit. All participants gave informed consent and the study was approved by the Institutional Review Board of the University of California, Irvine.

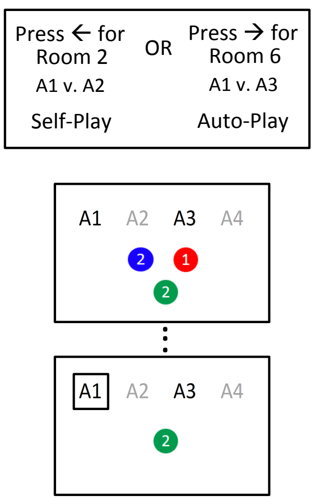

Figure 2: Task illustration, showing the room-choice screen at the beginning of a gambling round (left) and the choice (middle) and feedback (bottom) screens on a trial inside the selected room.

Task & Procedure The task is illustrated in Figure 2 and described in detail in [9]. Briefly, participants were instructed that they would assume the role of a gambler in a casino, playing a set of four slot machines (respectively labeled A1 through A4) that yielded three distinctly colored tokens (blue, green and red), each worth a particular amount of money, with different probabilities. In each of several gambling rounds, they were required to first select a room in which only two slot machines are available, knowing that they would be restricted to gamble only on the machines available in the selected room on several, 4-6, subsequent trials within that round. Two distinct probability distributions over the three possible token outcomes were used with the assignment of outcome distributions to slot machines being such that two of the slot machines (either A1 and A2 or A1 and A3, counterbalanced across subjects) always shared one distribution, while the other two slot machines shared the other distribution. This yielded a low (zero) outcome divergence for rooms in which the two available slot machines shared the same probability distribution (as in Figure 1A), and a high (0.49) outcome divergence for rooms in which slot machines had different outcome probability distribution (as in Figure 1B). The primary measure was the decision at the beginning of each round, between a high- and zero-divergence room: If a high degree of agency has intrinsic value, participants should prefer rooms with relatively high instrumental divergence.

While the action-token probabilities (which were pre-trained to criterion prior to gambling; see [9]) remained the same throughout the task, the monetary values of the tokens changed intermittently (every 4^{th} round on average). Consequently, although changes in value were explicitly announced, and the current values of tokens always printed on their surface (to facilitate the computation of expected utilities), a participant might find themselves in a room in which the expected utilities of the two available slot machines had suddenly been altered. These changes in token values served three purposes: First, they mimicked dynamic changes in the subjective utility of natural rewards. Second, they provided important criterion checks, confirming that participants were sensitive to differences in expected pay-offs, thus allowing an interpretation of performance in terms of classical theories of economic choice. Finally, they allowed us to vary expected monetary values in the opposite direction of instrumental divergence, pitting conventional reward against the value of flexible instrumental control.

Previous work has demonstrated a significant preference for perceptual diversity among obtainable outcomes [16,17]. In our task, the perceptual diversity of obtainable tokens was greater in high- than in zero-divergence rooms. Specifically, in zero-divergences rooms, there was a high probability of obtaining a blue token, a relatively low probability of obtaining a red token and a zero probability of obtaining a green token, with token colors counterbalanced across participants. In contrast, in high-divergence rooms, participants were able to obtain blue, red *and* green tokens, by switching between actions across trials. Consequently, even when the expected monetary gain of high- and zero-divergence rooms were identical, the perceptual diversity of obtainable outcomes was greater in high- than in zero-divergence rooms. One way to address the imbalance in perceptual diversity would be to make the outcome distributions in the zero-divergence rooms uniform, which maintains zero divergence while maximizing perceptual diversity. However, uniform outcome distributions would also yield maximum uncertainty about which outcome will occur given performance of an action; a serious confound given the reliably demonstrated aversion towards uncertainty (or risk) in human decision-making [18].

Here, instead, we address differences in perceptual diversity using a self- vs. auto-play manipulation. Imagine that you are allowed to choose between a high- and zero-divergence gambling room, but that once you make your selection, a computer algorithm chooses between available slot machines selecting each equally often by alternating across trials. Given such absence of voluntary choice, the high-divergence room no longer yields greater instrumental divergence (since in the absence of free choice, neither the high- nor zero-divergence condition can be considered instrumental) but still yields greater perceptual diversity than zero-divergence rooms. Consequently, if choices are driven by a desire to maximize perceptual diversity, rather than instrumental divergence, they should not differ depending on whether the participant or an alternating computer algorithm chooses between the slot machines in a room. In the current study, one room option was always self-play – participants choose freely between slot machines available in the selected room – and the other option was always auto-play – a computer algorithm alternated between machines across trials – as indicated by labels printed below options on the room-choice screen (see Figure 2). We predicted that, consistent with Mistry & Liljeholm [9], participant would prefer a high divergence room when it was self-play but not when it was auto-play, and a self-play room when it had high divergence but not when it had zero-divergence.

Recall that, in addition to differing in terms of self- vs. auto-play, and high vs. zero divergence, the two room options presented on the initial choice screen could differ in terms expected monetary pay-offs. Importantly, all monetary amounts were fictive, and participants were instructed at the beginning of the experiment that they would not receive any actual money upon completing the study. Nonetheless, given the previously demonstrated correspondence between real and fictive monetary rewards, in both behavioral choice and neural correlates [19-21], we predicted that participant's choice preferences would reflect sensitivity to monetary pay-offs. As noted, such sensitivity allowed us both to interpret performance in terms of classical theories of economic choice, and to assess a trade-off between instrumental divergence and monetary gain. Of primary interest, however, was the assessment of whether the preference for high instrumental divergence, previously demonstrated by Mistry & Liljeholm [9], would be modulated by individual differences in schizotypal traits, assessed, as detailed below, by the O-LIFE questionnaire.

The O-LIFE Questionnaire The Oxford-Liverpool Inventory of Feelings and Experiences (O-LIFE) is a four-scale questionnaire intended to assess dimensions of schizotypy [22], with scales corresponding, respectively to "unusual experiences", "cognitive disorganization", "introvertive anhedonia", and "impulsive non-conformity". In particular, unusual experiences and introvertive anhedonia are phenomenologically related, respectively, to positive and negative symptoms of schizotypy and, thus, are of primary interest here. Specifically, we hypothesized that differences along each of these two dimensions would predict individual differences in the preference for instrumental divergence (i.e., for a combination of high-divergence and self-play). The O-LIFE questionnaire was administered either immediately before or immediately after the gambling task, counterbalanced across participants.

Computational Variables As in Mistry & Liljeholm [9], we formalize instrumental divergence as the Jensen-Shannon (JS) divergence [23] of the token probability distributions for the two slot machines available in a given room. Let P_1 and P_2 be the respective token probability distributions for the two machines available in a given room, let O be the set of possible token outcomes, and $P(o)$ the probability of a particular token outcome. The instrumental (Jensen-Shannon) divergence is:

$$ID = \frac{1}{2}\sum_{o\in O}\log\left(\frac{P_1(o)}{P_*(o)}\right)P_1(o) + \frac{1}{2}\sum_{o\in O}\log\left(\frac{P_2(o)}{P_*(o)}\right)P_2(o),$$

where

$$P_* = \frac{1}{2}\left(P_1 + P_2\right)$$

Note that instrumental divergence is defined with respect to the sensory, rather than motivational, features of outcome states – since subjective utilities are constantly changing, motivational features are intrinsically unstable as a basis for agency – and with respect to distributions associated with *available* action alternatives, rather than observed actions or Pavlovian cues – since only freely chosen actions confer agency and flexible instrumental control.

We defined the *expected monetary value* of a room as the sum over the products of token probabilities and monetary token utilities given a particular slot machine, summed over the two machines available in the room:

$$EV = \sum_{a\in A}\sum_{o\in O} p(o \mid a)u(o)$$

where A is the set of machines available in a room (e.g., A1 and A2), O is, again, the set of possible token outcomes, $p(o|a)$ is the probability of a particular token outcome o conditional on a particular machine a, and $u(o)$ is the monetary value of token outcome o. The unpredictability (i.e., Shannon entropy) of token outcomes given a particular slot machine was held constant across all machines and rooms.

Results

Mean choice proportions for high over zero divergence, and for self over auto play, are shown at the top of Figure 3. Consistent with the findings by Mistry & Liljeholm [9], participants preferred the high-divergence over the zero-divergence room significantly more often when the high-divergence room was associated with self-play (and the zero-divergence room with auto-play) than when the high-divergence room was associated with auto-play (and the zero-divergence room with self-play), *t(59)=2.21, p=0.03*

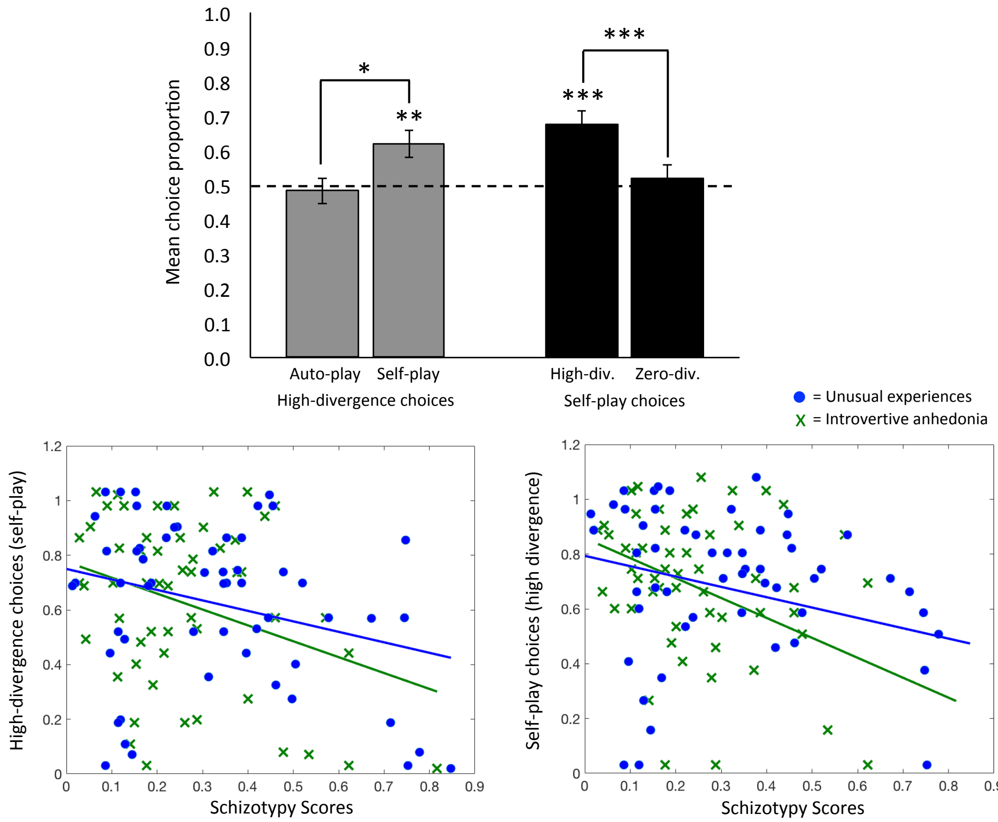

Figure 3: Choice proportions and their correlation with Schizotypy dimensions. Top: Mean proportions of high- over zero-divergence choices (left) for blocks in which the high-divergence option was auto-play versus blocks in which the high-divergence option was self-play, and mean proportions of self- over auto-play choices (right) for blocks in which both options had high-divergence (High-div.) versus blocks in which both options had zero-divergence (Zero-div.). Dashed line indicates chance performance. Error bars = SEM. * = $p < 0.05$, ** = $p < 0.005$, *** = $p < 0.0001$. Bottom: Residual plots of choice proportions and schizotypy scores, showing the proportion of high-divergence choices given that the high divergence option was self-play on the left and the proportion of self-play choices given high-divergence on the right.

Cohen's *d=0.50*. Indeed, when the high-divergence room was auto-play and the zero-divergence room was self-play, selection of the high-divergence room did not deviate significantly from chance, *t(59)=0.44, p=0.66*. Conversely, participants preferred self-play over auto-play significantly more often when choosing between two high-divergence rooms than when choosing between two zero-divergence rooms, *t(59)=4.79, p<0.0001, d=0.53*. Again, when choosing between two zero-divergence rooms, the preference for self-play did not deviate significantly from chance, *t(59)=0.56, p=0.57*.

This pattern of results demonstrates that, rather than perceptual outcome diversity, or the mere presence of free choice, it is the flexible control afforded by high instrumental divergence that is of value.

To assess how the preference for high instrumental divergence (i.e., for the combination of high divergence and self-play) related to positive and negative schizotypal traits, we computed a set of partial correlations between choice proportions and schizotypy scores (measured as points scored out of total possible), illustrated by residual plots in Figure 3 (bottom panels), controlling for the number of training blocks required to reach criterion accuracy on ratings of token probabilities prior to the gambling phase, and for the order of administration of the O-LIFE questionnaire. Specifically, we considered associations between 1) unusual experiences scores and the proportion of high-divergence choices given self-play, *r=-0.29, p=0.03,* 2) introvertive anhedonia scores and the proportion of high-divergence choices given self-play, *r=-0.33, p<0.01,* 3) unusual experiences scores and the proportion of self-play choices given high divergence, *r=-0.29, p=0.03,* and 4) introvertive anhedonia scores and the proportion of self-play choices given high divergence, *r=-0.42, p<0.001*. In contrast, we did not expect positive or negative dimensions of schizotypy to be significantly related to choice proportions for options that did not involve high instrumental divergence (i.e., rooms with high divergence but auto-play, or with zero divergence and self-play) and, indeed, no such associations were found.

Finally, we investigated whether participants were sensitive to expected monetary pay-offs, and whether such sensitivity was modulated by instrumental divergence. Specifically, we assessed the preference for rooms with a greater monetary gain when divergence differed in the same versus opposite direction (i.e., when the room with a greater monetary gain also had the greater level of divergence versus when the room with the lesser greater monetary gain had the greater level of divergence), and when the high-divergence room was auto-play versus self-play. A 2-by-2 repeated measures analysis of variance (ANOVA) with player type (auto vs. self) and direction of difference in divergence (same vs. opposite of monetary pay-offs) as factors, revealed a significant interaction $F(1,59)=4.27, p<0.05, \eta_p^2=0.067$. Specifically, as can be seen in Figure 4, when the high divergence room was auto-play, the preference for the room with greater monetary pay-off was equally strong whether divergence differed in the same or opposite direction as monetary gain across rooms, $t(59)=0.38, p=0.70$, Bayes Factor in favor of the null hypothesis[25] ($BF_{01})=6.589$ In contrast, when the high-divergence room was self-play, yielding high *instrumental* divergence, participants' preferences for the room with a greater monetary pay-off was significantly greater when instrumental divergence differed in the same direction across rooms than when it differed in the opposite direction, $t(59)=3.05, p=0.004$ $d=0.65$. Indeed, when instrumental divergence differed across rooms in the opposite direction of monetary gain, the mean choice proportion did not deviate significantly from chance, $t(59)=0.51, p=0.61,$ suggesting a trade-off between the utility of money and agency. The strong deviation from chance for all other choice proportions plotted in Figure 4, all *p's*<0.0001, clearly demonstrates a sensitivity to monetary pay-offs in our task. Notably, no schizotypy dimension significantly predicted the strong preference for the option with the greater monetary pay-off when high divergence was associated with auto-play (i.e., when instrumental divergence was ruled out as a source of the preference), all *p's* > 0.10.

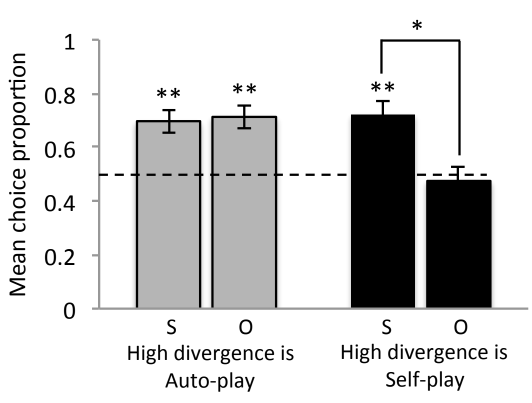

Figure 4: Mean proportion of choosing the room with the greater expected monetary pay-off, when the high-divergence room was auto-play (left side) versus when it was self-play (right side), given that divergence differed across rooms in the same (S) versus opposite (O) direction of expected monetary gain. Dashed line indicates chance performance. Error bars = SEM. * = $p < 0.005$, ** = $p < 0.0001$.

Discussion

The current study investigated the extent to which individual differences in schizotypal traits predicted behavioral preferences for high instrumental divergence – a formal index of agency. We found that both positive (unusual experiences) and negative (introvertive anhedonia) dimensions of schizotypy were negatively correlated with a preference for high instrumental divergence. In contrast, no significant relationships were observed between schizotypy scores and preferences for options that lacked instrumental divergence but were instead associated with high perceptual diversity or the mere presence of free choice. The strongest association with instrumental divergence (i.e., greatest |r|) appeared to be for the negative schizotypy dimension of introvertive anhedonia, suggesting that the underlying process may be tied to motivation. However, critically, introvertive anhedonia did not predict preferences for greater monetary pay-offs, specifically implicating the utility of agency as a target for hedonic modulation in schiotypy.

Our findings contribute to a growing literature highlighting the relationship between psychosis and the sense of agency (SOA). Notably, studies on SOA often manipulate outcome entropy, contingency, contiguity, or the mere presence of free choice – factors that profoundly impact predictive learning, and that have themselves been implicated in mood and thought disorders[24]. In contrast, instrumental divergence provides a novel measure of agency that varies independently of outcome contiguity and predictability, and without eliminating volition, thus disambiguating the contribution of basic instrumental processes, such as simple contingency learning, to the apparent dysregulation of agency in schizophrenia. Moreover, unlike previous assessments of SOA, our paradigm dissociates motivational aspects of flexible instrumental control from purely cognitive representations, at both behavioral and neural levels. By relating agency to processes underpinning value-based choice, we are able to explore uncharted lines of inquiry regarding the respective contributions of affective and cognitive impairments to aberrant SOA.

The finding that schizotypal traits in healthy individuals modulate a preference for high instrumental divergence suggests that effects of instrumental divergence might also be significantly altered in clinical populations, potentially accounting for aspects of behavioral pathology in schizophrenia. Notably, the supramarginal gyrus of the inferior parietal lobule, implicated in neural computations of instrumental divergence by Liljeholm et al [10], has been frequently shown to differ volumetrically across schizophrenic and neurotypical individuals [11-15], highlighting a possible anatomical basis for any differences in cognitive or motivational representations of instrumental divergence. Future research will be aimed at assessing whether individuals diagnosed with schizophrenia differ from healthy controls in their behavioral preference for high instrumental divergence and in underlying neural value computations.

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