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Journal
Journal of Psychopathology and Clinical Science, 124(3)

ISSN
2769-7541

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Publication Date
2015-08-01

DOI
10.1037/abn0000067

Peer reviewed

HHS Public Access

Author manuscript

J Abnorm Psychol. Author manuscript; available in PMC 2015 September 18.

Published in final edited form as:

J Abnorm Psychol. 2015 August ; 124(3): 507–518. doi:10.1037/abn0000067.

Examining Associations between Psychosis Risk, Social Anhedonia, and Performance of Striatum-Related Behavioral Tasks

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Abstract

Both psychosis and anhedonia have been associated to some extent with striatal functioning. The current study examined whether either psychosis risk or social anhedonia was associated with performance on three tasks related to striatal functioning. Psychosis risk participants had extremely elevated Perceptual Aberration/Magical Ideation (PerMag) scores (*n*=69), with 43% of psychosis risk participants also having semi-structured interview-assessed psychotic-like experiences which further heightens their risk of psychotic disorder (Chapman, Chapman, Kwapil, Eckblad, & Zinser, 1994). Compared to both extremely elevated Social Anhedonia (*n*=60) and control (*n*=68) groups, the PerMag group exhibited poorer performance on two of the striatum-related tasks, the Weather Prediction Task (WPT) and the Learned Irrelevance Paradigm, but not on Finger Tapping. In addition, PerMag participants with psychotic-like experiences were especially impaired on the WPT. Overall, this study arguably provides the first evidence that psychosis risk but not social anhedonia is associated with performance on the WPT, a task thought to be strongly associated with activation in the associative striatum, and also suggests that the WPT might be especially useful as a behavioral measure of psychosis risk.

Keywords

positive schizotypy; social anhedonia; psychotic-like experiences; reward learning; novelty; salience

Both psychosis and anhedonia have been associated to some extent with striatal functioning. Psychotic disorders involve the symptoms of delusions and hallucinations and the most replicated neurobiological correlate of psychosis risk and psychotic disorders is increased striatal dopamine (Howes, Fusar-Poli, Bloomfield, Selvaraj, & McGuire, 2012). For

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instance, a number of in vivo imaging studies have reported striatal dysfunction, including increased striatal dopamine, in people at risk for psychosis (e.g., Dandash et al., 2013; de la Fuente-Sandoval et al., 2011; Egerton et al., 2013; Howes et al., 2009; Juckel et al., 2012; Morris et al., 2013). However, the relationship between performance on striatum-related behavioral tasks and psychosis risk or psychotic disorder is still unclear (Chun, Minor, & Cohen, 2013; Evans, Gray, & Snowden, 2007). Anhedonia, which predicts future onset of schizophrenia-spectrum disorders (Gooding, Tallent, & Matts, 2005; Kwapil, 1998) and poor outcome of these disorders (Green, Hellemann, Horan, Lee, & Wynn, 2012; Kring, Gur, Blanchard, Horan, & Reese, 2013), has also been associated with striatal dysfunction. In particular, multiple imaging studies with people with schizophrenia have found that negative symptoms, perhaps especially anhedonia symptoms, are associated with decreased activation in at least some areas of the striatum (Dowd & Barch, 2012; Juckel et al., 2006). However, the presence of striatal-related behavioral deficits in anhedonia in at risk populations is still unclear (Padrao, Mallorqui, Cucurell, Marco-Pallares, & Rodriguez-Fornells, 2013). Furthermore, several previous studies involving first degree relatives of individuals with schizophrenia have found striatum dysfunction (Wagshal et al., 2012; Wagshal et al., 2014a; Wagshal et al., 2014b; Weickert et al., 2010; for a somewhat related non-familial risk study involving elevated schizotypal traits, see Skilleter et al., 2014). However, it is not clear from this research what particular aspect of disorder risk, such as psychosis risk, level of anhedonia, or neither, is specifically associated with striatum dysfunction. Hence, the goal of the current research was to examine whether either psychosis risk or social anhedonia (SocAnh) was associated with impaired performance on behavioral tasks thought to be strongly related to striatal functioning.

In general, there are multiple reasons it would be useful to identify behavioral correlates of psychosis risk and SocAnh. The most direct evidence for striatal dopamine involvement in psychosis risk comes from Positron Emission Tomography (PET) which is both prohibitively expensive and too invasive for widespread research or clinical use (Howes et al., 2012). Behavioral tasks have the potential to be more widely useful measures of psychosis risk detection than PET (Fusar-Poli et al., 2012). In contrast to PET, other imaging modalities such as functional Magnetic Resonance Imaging (fMRI) could potentially be clinically useful to measure psychosis risk and SocAnh (Fornito et al., 2013). However, fMRI often relies upon task-evoked activity and it is important to first identify behavioral tasks associated with psychosis risk or SocAnh that could then be used with fMRI to assess striatal dysfunction (Gazzaley & D'Esposito, 2005). Further, behavioral measures of psychosis risk or SocAnh could also be convenient targets for treatment research as improvements in behavioral task performance could be a useful marker of normalized striatal functioning and treatment success (Carter, Parnas, Urfer-Parnas, Watson, & Mednick, 2011). Behavioral measures could also be useful in computational modeling studies. Detailed computational models of striatal functioning have been developed (Frank, 2011) and these could be important for elucidating specific mechanisms involved in psychosis risk or SocAnh. However, these models typically rely on having data on behavioral task performance that can then be used in order to conduct model testing and assess model fit. Yet, as previously mentioned, the relationship between psychosis risk and

SocAnh and striatum-related behavioral tasks and the presence of striatal-related behavioral deficits in at risk populations are still unclear (e.g., Chun et al., 2013; Padrao et al., 2013).

Examining behavioral correlates of either psychosis risk or SocAnh can also provide important converging evidence about the nature of striatal dysfunction. The striatum is a heterogeneous structure, with recent striatal parcellation research elucidating cortical connectivity patterns of subregions of the striatum (e.g., Draganski et al., 2008; Tziortzi et al., 2013). The striatum is the input layer of the basal ganglia (Gerfen & Surmeier, 2011) and is critically involved in the cortico-striatal-pallido-thalamic circuits, or the functional loops composed of striatal regions projecting to the thalamus, which in turn projects to cortical regions (e.g., the dorsolateral prefrontal cortex, medial prefrontal cortex, premotor cortex; Alexander, Crutcher, & DeLong, 1990; Draganski et la., 2008; Tziortzi et al., 2013) and then back to the striatum. Parcellation research indicates that different striatal subregions can be distinguished based on white matter and resting state functional connectivity (e.g., Draganski et al., 2008), including (a) a limbic region involved in responding to novel stimuli and reward-related stimuli (Guitart-Masip, Bunzeck, Stephan, Dolan, & Duzel, 2010; Lisman & Grace, 2005), (b) an associative (i.e., “executive”; Levitt et al., 2013) region involved in learning, including learning how to respond to particular stimuli in order to obtain reward (Lozano, Serafin, Prado-Alcala, Roozendaal, & Quirarte, 2013; Mattfeld & Stark, 2011), and (c) a motor region involved in motor execution (e.g., Marchand et al., 2008; Pool, Rehme, Fink, Eickhoff, & Grefkes, 2013) including the planning and execution of learned motor sequences (e.g., Lehericy et al., 2005). In the current research, participants completed three behavioral tasks that are strongly related to cortico-striatal-pallido-thalamic circuits and previously associated with striatal activation: the Weather Prediction Task, the Learned Irrelevance Task, and the Finger Tapping Task.

The Weather Prediction Task is a probabilistic reward learning task (Knowlton, Squire, Paulsen, Swerdlow, & Swenson, 1996). Several brain imaging studies have reported strong striatum activation during performance of this task (e.g., Poldrack et al., 2001; Weickert et al., 2009). Furthermore, there is evidence that schizophrenia is associated with impaired performance (Weickert et al., 2013) and reduced striatum activation on this task (Weickert et al., 2009). Hence, the Weather Prediction Task is thought to be strongly, although not exclusively (e.g., prefrontal and parietal cortices; Poldrack et al., 2001; Weickert et al., 2009), related to the striatum.

The second striatum-related task, the Learned Irrelevance Paradigm (Young et al., 2005), was developed as a within subjects design to measure latent inhibition in humans (Young et al., 2005; for the close, some would argue synonymous, relationship between the constructs of learned irrelevance and latent inhibition, see Gray & Snowden, 2005). Animal studies indicate that the striatum is activated by latent inhibition tasks (Gray et al., 1995; Meyer & Louilot, 2011), with the novelty component of latent inhibition tasks especially found to activate the striatum (Schmajuk, Cox, & Gray, 2001). Furthermore, lesions of the striatum and increased dopamine in the striatum impair the ability to perform latent inhibition tasks (Gal et al., 2005; Gray, 1998). Hence, the Learned Irrelevance Paradigm used in the current study is thought to be strongly, but not exclusively (e.g., hippocampus; prefrontal cortex; Young et al., 2005), related to the striatum.

In addition, a sizable number of previous studies (at least 17) have found that questionnaires assessing psychotic-like beliefs and experiences (i.e., positive schizotypy) are associated with impaired performance on latent inhibition tasks (e.g., Gray, Fernandez, Williams, Ruddle, & Snowden, 2002; Schmidt-Hansen & Honey, 2014). Hence, it could be argued that latent inhibition tasks are one of the best replicated behavioral correlates of psychosis risk. However, there are some important limitations in all previous psychosis risk latent inhibition studies (Evans et al., 2007). For instance, the sample sizes in arguably all of these studies are quite small for psychosis risk research, with the clear majority of studies involving unselected (i.e., non-extreme scoring) samples with less than 50 people per study or per latent inhibition task condition. Hence, it is still unclear whether either psychosis risk or SocAnh is associated with performance on latent inhibition tasks.

The last striatum-related task that participants completed was the Finger Tapping Task (Reitan, 1969). Several imaging studies have found that finger tapping task performance is associated with activation in the striatum (Delmaire et al., 2005; Moritz, Haughton, Cordes, Quigley, & Meyerand, 2000). Moreover, there is evidence that individuals with striatum deficits, such as individuals with Parkinson's disease, show deficits on this task (e.g., Teo, Rodrigues, Mastaglia, & Thickbroom, 2013). Hence, the Finger Tapping Task is thought to be strongly, but not exclusively (e.g., sensorimotor cortex; supplementary motor area; thalamus; Lehericy et al., 2005; Moritz et al., 2000) related to the striatum. There is previous evidence that psychosis risk is related to movement abnormalities (e.g., Mittal et al., 2007). However, only three studies have examined finger tapping in people receiving clinical services with high psychotic disorder risk compared to controls and a meta-analyses of those studies found a small but non-significant effect size group difference with a tendency for decreased taps in the risk group (Giuliano et al., 2012). Furthermore, one other study with a relatively small sample size (n=50) in an unselected sample found that decreased finger tapping was associated with questionnaires assessing psychotic-like beliefs and experiences (Asai, Sugimori, & Tanno, 2009). Hence, there is some preliminary evidence that psychosis disorder risk might be associated with decreased finger tapping, however this has not been looked at in relation to SocAnh.

In the current study, we examined performance of striatum-related behavioral tasks both in people at risk for psychotic disorder and people with extremely elevated SocAnh at risk for schizophrenia-spectrum disorders. In measuring psychosis risk, we used a psychometric high risk approach and identified people with extreme scores on the Wisconsin Schizotypy Perceptual Aberration and/or Magical Ideation Scales (i.e., PerMag). To further assess psychosis risk, we also rated psychotic-like experiences using the Structured Interview for Prodromal Symptoms. Thus, these individuals are at risk for psychosis because they exhibit both psychometric and semi-structured interview-rated evidence of psychotic-like experiences, which Chapman et al. (1994) found predicted increased risk for psychotic disorder (14% vs. 1% in controls). Therefore, we also divided our PerMag group by whether or not they had evidence of significant psychotic-like experiences at semi-structured interview. Hence, overall, the current research examined whether psychosis risk or social anhedonia was associated with impaired performance either on the striatum-related Weather Prediction Task, Learned Irrelevance Paradigm, or the Finger Tapping Task. It was

predicted that both the Psychosis Risk group and the SocAnh group would exhibit impairment on these striatum-related tasks.

Methods

Participants

Participants were undergraduate Introduction to Psychology students at a large Midwestern university who participated for course credit. Participants were recruited as in our previous research that has successfully combined a questionnaire psychometric high risk approach with psychotic-like experience semi-structured interview (Cicero, Martin, Becker, Docherty, & Kerns, 2014). Participants in the PerMag group (*n*=69; 66.7% women, mean age=18.49, *SD*=0.76, 66.7% European American, 14.5% African American, 2.9% Asian American, 4.3% Latino/Latina, 2.9% biracial, and 8.7% other) scored greater than 1.96 standard deviations (SDs) above the same sex mean on the Perceptual Aberration (PerAb) or Magical Ideation (MagicId) scales, or scored three SDs above the mean for the sum of standardized PerAb and MagicId scores (with norms based on a large unselected college student sample; Kerns & Berenbaum, 2000). Following Chapman et al. (who interviewed participants using the SADS and then rated psychotic-like experiences using the Wisconsin Manual for Assessing Psychotic-like Experiences), we also divided the PerMag group using the Structured Interview for Prodromal syndromes (SIPS) by whether participants had at least moderate lifetime psychotic-like experiences (i.e., a SIPS score ≥3, with 3="moderate" symptom severity; Miller et al., 2003) on either the Perceptual Abnormalities/Hallucinations or the Unusual Thought Content/Delusional Ideation SIPS subscales (note that Chapman et al., 1994, in rating psychotic-like experiences, also focused only on these two types of symptoms; also, given that Chapman et al. found that people without at least moderate levels of these symptoms were not at increased risk of psychotic disorder. This suggests that if we used a broader set of semi-structured interview rated psychotic-like experiences in the current study that this would only decrease the level of psychotic disorder risk in this group; in current study, PerMag participants with significant, i.e., at least moderate, psychotic-like experiences, *n*=30; 55.2% women, mean age=18.52, *SD*=0.83, 63.3% European American, 10.0% African American, 3.3% Asian American, 6.7% Latino/Latina, 6.7% biracial, and 10.0% other; PerMag participants without significant psychotic-like experiences, *n*=39; 76.9% women, mean age=18.46, *SD*=0.72, 69.2% European American, 17.9% African American, 2.6% Asian American, 2.6% Latino/Latina, and 7.7% other). We found that 43% of PerMag participants had significant psychotic-like experiences on the SIPS, which is comparable to the 38% of PerMag participants that Chapman et al. (1994) found had significant subthreshold psychotic symptoms.

Participants in the SocAnh group (*n*=65; 70.8% women, mean age=18.74, *SD*=0.89, 61.5% European American, 16.9% African American, 3.1% Asian American, 6.2% Latino/Latina, 3.1% biracial, and 7.7% other) scored greater than 1.96 SDs above the same sex mean on the SocAnh scale and less than 1.96 SDs above the mean on both the PerAb and MagicId scales. Five of the 65 participants in the SocAnh group had at least moderate lifetime psychotic-like experiences on the Perceptual Abnormalities/Hallucinations or Unusual Thought Content/ Delusional Ideation subscales of the SIPS. Participants in the control group (*n*=68; 63%

women, mean age=18.84, *SD*=1.14, 83.8% European American, 4.4% African American, 1.5% Asian American, 2.9% Latino/Latina, 1.5% biracial, and 5.9% other) scored less than 0.5 SDs above the mean on the PerAb, MagicId, and SocAnh scales. In addition, to more clearly examine differences between the control group and the psychosis risk and SocAnh group, the control group participants had to be rated less than 2 on both the Perceptual Abnormalities/Hallucinations and the Unusual Thought Content/Delusional Ideation subscales of the SIPS (1=questionably present symptom, 2=mild symptoms; therefore, these lifetime psychotic-like experiences in the control participants were no more than "questionably present").

There were no significant differences between the groups on the demographic variables sex, age, or ethnicity [e.g., for sex in an analysis involving PerMag, control, and SocAnh, $\chi^2(2)=.78$, $p=.68$; for ethnicity, $\chi^2(10)=5.82$, $p=.83$]. Within the PerMag group, there was a trend for the PerMag group with psychotic-like experiences and the PerMag group without psychotic-like experiences to differ on sex, $\chi^2(1)=3.20$, $p=.07$. Hence, to explore whether sex was statistically related to group differences (Miller & Chapman, 2001), we re-ran all analyses within the PerMag group using sex as a covariate, with results being substantively unchanged.

Materials

Wisconsin Schizotypy Scales—Participants completed the PerAb Scale (Chapman, Chapman, & Raulin, 1978; $\alpha=.90$) and the MagicId Scale (Eckblad & Chapman, 1983; $\alpha=.86$). Previous research has found that extreme scorers on the PerAb and MagicId are at increased risk for future psychosis (Chapman et al., 1994). Participants also completed the SocAnh Scale (Eckblad, Chapman, Chapman, & Mishlove, 1982; $\alpha=.88$). There is evidence that people with extreme SocAnh scores are at increased risk for schizophrenia-spectrum disorders (Gooding et al., 2005; Kwapil, 1998). Lastly, participants completed the Chapman Infrequency Scale (Chapman & Chapmen, 1983), a 13-item true-false scale to measure careless and invalid responding. Based on previous research (e.g., Chapman et al., 1994), participants who endorsed three or more items were excluded.

Structured Interview for Prodromal Symptoms—The Structured Interview for Prodromal Syndromes (Miller et al., 2003) is a semi-structured diagnostic interview and is a valid measure of psychotic-like experiences that predicts risk for future psychotic disorder (Miller et al., 2002; Miller et al., 2003). The SIPS was designed to detect attenuated positive symptoms (i.e., psychotic symptoms below the threshold of full-blown psychotic symptoms; Marshall et al., 2014; Miller et al., 2003). Its developers did not say it was designed to for use only in treatment seeking samples, but it has mostly been used in clinical populations at ultra-high risk for psychosis onset. In the current research, we have used the SIPS to assess psychotic-like experiences in a non-clinical population to identify people at increased risk of future psychotic disorder (for other research using the SIPS in non-treatment seeking samples: Chen et al., 2014; Cicero et al., 2014; Stowkowy & Addington, 2013; Veijola et al., 2013). As previously mentioned, we focused on two core lifetime psychotic SIPS items, Perceptual Abnormalities/Hallucinations and the Unusual Thought Content/Delusional Ideation. These items were scored in adherence with standard SIPS scoring (i.e., from 0-6

with regard to frequency, duration, distress, and conviction of the individual symptoms; Miller et al., 2002; 2003). In addition, following Chapman et al. (1994) and their assessment of psychotic-like experiences, we focused on whether people ever had psychotic-like experiences in their lifetime. On the SIPS, symptoms are rated on a 0-6 scale, with a score of 3 indicating moderate symptom level and 6 indicating "severe and psychotic" (in current study, no participant scored a 6 on any of the domains of the SIPS). We deviated from the standard SIPS rating approach in that we rated both paranoid and non-paranoid unusual thought content under the item Unusual Thought Content (without deviating from the SIPS in our rating of the item Suspiciousness). All the SIPS interviews were videotaped and conducted by two graduate student interviewers extensively trained in SIPS administration and scoring (NRK & EAM; inter-rater reliability between the two raters was .93 for the Perceptual Abnormalities/Hallucinations and .95 for Unusual Thought Content/Delusional Ideation). Interviewers were blind to group membership and questionnaire scores of the participants.

Weather Prediction Task—On this probabilistic reward learning task, participants saw cards on the computer screen and used the cards to predict the weather, either rain or shine, which occurred with equal frequency (for more on this task, see Knowlton et al., 1996; Weickert et al., 2009). To examine whether groups differed in their rate of learning over the course of the task (which involved 120 total trials), accuracy data was analyzed using a multilevel model, specifically in a group X trial multilevel logistic regression using the glmer procedure in R (Ihaka & Gentleman, 1996), with participants modeled as random intercepts. Using a multilevel model analysis allowed us to estimate whether risk groups would exhibit less learning on this task as indicated by a smaller positive slope in their rate of improvement in accuracy.

In addition, following previous research (Gluck, Shohamy, & Myers, 2002; Shohamy, Myers, Onlaor, & Gluck, 2004), we also examined strategy use on the Weather Prediction Task. There are three identified strategies on this task: *singleton*, *one-cue*, and *multi-cue*, with singleton considered the worst and with multi-cue only being frequently used after extended performance of the task (i.e., after multiple sessions; Shohamy et al., 2004). To examine improvement in strategy use, following previous research (e.g., Weickert et al., 2009), we divided the task by quartiles and we then examined strategy use on the very first quartile and on the fourth and final quartile. It was expected that a greater proportion of risk group participants would adopt the less advanced strategy (i.e., a greater proportion of the worst singleton strategy than the other two strategies) at the end of the task.

Learned Irrelevance Paradigm—On this task (Orosz, Feldon, Gal, Simon, & Cattapan-Ludewig, 2008; Young et al., 2005), participants were instructed to press the "X" button on the keyboard as soon as the target stimulus (the letter "X") appeared on the screen. Participants were told that some non-target letters might help to predict the occurrence of the target letter. There were three different block types: random, novel, and pre-exposed. On random blocks, the non-target letters (e.g., "A") that immediately preceded the target letter did not reliably predict the occurrence of the target letter. On novel blocks, one novel (i.e., not previously seen) non-target (e.g., "B") letter always preceded and therefore reliably

predicted the occurrence of the target letter on that one block. Hence, participants were expected to be faster on novel blocks than on random blocks because on novel blocks, a novel and salient stimulus reliably predicted the occurrence of the target letter. On pre-exposed blocks, one non-target letter (e.g., "A") reliably predicted the occurrence of the target letter on that block, but this predictive non-target letter had been previously seen (e.g., during a random block) and was therefore not novel. Hence, participants were expected to be slower on pre-exposed than novel blocks because on pre-exposed blocks participants had to learn from a predictive stimulus that was neither novel nor salient and they also had to overcome to what extent this stimulus had been previously learned to be non-predictive of the target.

Following previous research (Gal et al., 2005; Orosz et al., 2008; Orosz et al., 2011), we examined two different scores thought to be related to striatum functioning, the *associative learning score*, which was the extent to which people were faster on novel than on random blocks, and the *learned irrelevance score*, which was the extent to which people were faster on novel than on pre-exposed blocks. Given the role of the striatum in novelty processing (Schmajuk et al., 2001), striatum impairment should reduce both associative learning and learned irrelevance scores (i.e., it should make performance of novel blocks more like performance of the other blocks). Hence, it was expected that risk groups should be associated with both decreased associative learning and learned irrelevance.

Finger Tapping Task—On this task (Reitan, 1969), participants hit a keyboard spacebar as fast as possible for ten 10-second trials, alternating between dominant and non-dominant hands. Following previous research (e.g., Ito, Kado, Suzuki, & Anod, 2013), we examined three related movement scores: average number of taps per trial, intertap interval, and intertap interval variability. Three participants (1 PerMag, 2 SocAnh) had no recorded responses for some of their initial trials (two missing 4 trials, one 2 trials). We suspect that on those trials they hit the wrong button (and eventually realized and corrected this) and we excluded the trials without recorded responses from their data. Excluding their data altogether left the results essentially unchanged.

Current Mood—To examine whether task performance was associated with current mood, participants completed the Positive and Negative Affect Schedule (PANAS: Watson, Clark, & Tellegen, 1988; α=.88 for positive affect, α=.75 for negative affect).

Procedure

The current study took approximately 120 minutes and included some other unrelated tasks. All measures and tasks were computer administered through E-prime software (Psychology Software Tools, 2006), with the exception of the SIPS. Cohen's *d* is included in all analyses as a measure of effect size.

Results

Weather Prediction Task (WPT)

First, we examined overall performance using a multilevel logistic regression analysis of accuracy over time (i.e., across trials). As can been seen in Table 1, there was a main effect of time, Z=2.31, p<.05, d=.33, as accuracy on average improved over time (e.g., for controls, effect of time Z=3.95, p<.001, d=1.09). However, there was also a significant time X group interaction, Z=4.82, p<.001, d=.72, indicating group differences in improvement over time.

We next examined whether either risk group exhibited significantly less overall improvement in performance than the other groups. As can be seen in Table 1, the PerMag group exhibited significantly less improvement in performance over time than either the control group, Z=-4.79, p<.001, d=.90, or the SocAnh group, Z=-3.57, p<.001, d=.65. In contrast, the control group did not differ significantly from the SocAnh group, Z=-1.16, p=.25, d=.20.

Thus far, we have reported less improvement over time on the WPT in the PerMag group in comparison to the other two groups. Next we examined whether the PerMag group that also had significant semi-structured interview-rated psychotic-like experiences exhibited less improvement over time than the PerMag group that did not have significant psychotic-like experiences. As can be seen in Table 1, the PerMag group with psychotic-like experiences exhibited significantly less improvement over time than the PerMag group without psychotic-like experiences, Z=-2.90, p<.005, d=.74. Furthermore, the PerMag group with psychotic-like experiences showed significantly less improvement over time than both the control, Z=-5.56, p<.001, d=1.36, and SocAnh groups, Z=-4.60, p<.001, d=1.07, with the between-group effect sizes being very large. The PerMag group without psychotic-like experiences also exhibited significantly less improvement over time than the control group, Z=-2.62, p<.01, d=.52, but not the SocAnh group, Z=-1.59, p>.05, d=.32, with the between-group effect sizes being moderate to small. Hence, there was evidence that impaired reward learning over time was especially pronounced in PerMag participants with semi-structured interview-rated psychotic-like experiences, who have been found to be at greatest risk of psychotic disorder (Chapman et al., 1994).

Next we examined whether the PerMag group who also had significant psychotic-like experiences were less likely to adopt an advanced strategy over time than the PerMag group that did not have psychotic-like experiences. In analyzing initial strategy use during the first quartile, there were no significant between-group differences, with if anything a smaller proportion of the PerMag group with psychotic-like experiences using the simpler singleton strategy (p=.47). However, by the fourth quartile, a significantly smaller proportion of the PerMag group with psychotic-like experiences exhibited advanced strategy use (i.e., a greater proportion used the singleton strategy) compared to the PerMag group without psychotic-like experiences, $\chi^2(1)$=4.61, p<.05, d=.54. In addition, only the PerMag group with psychotic-like experiences exhibited less advanced fourth quartile strategy use than the control, $\chi^2(1)$=7.85, p<.01, d=.59, and SocAnh groups, $\chi^2(1)$=4.59, p<.05, d=.45 (and again, note that for the 1st quartile, the PerMag group with psychotic-like experiences, if anything, was less likely to initially adopt the simpler strategy; 1st quartile comparison with controls:

p=.16; comparison with SocAnh: *p*=.16). In contrast, the PerMag group without psychotic-like experiences did not differ significantly in fourth quartile strategy use from the control, $\chi^2(1)=.13$, *p*=.71, *d*=.07, and SocAnh groups, $\chi^2(1)=.03$, *p*=.87, *d*=.03. Hence, there was evidence that impaired probabilistic learning strategy use was especially pronounced in PerMag participants with significant psychotic-like experiences.

Learned Irrelevance Paradigm (LIP)

On this task, we first examined overall performance in a 3 (trial type: random, novel, pre-exposed) X 3 (group: PerMag, control, SocAnh) repeated measures ANOVA for reaction time (RT). As can be seen in Table 2, as expected, there was a main effect of trial type, $F(2,199)=89.24$, $p<.001$, $d=1.90$, as RTs for the three trials types all differed significantly from each other, with participants exhibiting both significant associative learning, $F(2,199)=7.60$, $p<.005$, $d=.55$, and learned irrelevance effects, $F(2,199)=3.07$, $p<.05$, $d=.35$. In addition to the main effect of trial type, there was also a significant trial type X group interaction, $F(4,398)=4.45$, $p<.005$, $d=.42$.

Next, we examined performance on random blocks to test whether either risk group displayed general poor performance on this task. There were no between-group differences for either RT or corrected hit rate, i.e., target hit rate minus false alarm rate. For example, the PerMag group did not significantly differ from the control (RT: *p*=.45, *d*=.13; corrected hit rate, i.e., target hit rate minus false alarm rate: *p*=.47, *d*=.12) and SocAnh groups (RT: *p*=.67, *d*=.08; corrected hit rate: *p*=.42, *d*=.14). Moreover, SocAnh and control groups also did not significantly differ, *p*s≥.23. Hence, the risk groups did not exhibit poor performance on all aspects of the LIP.

Next, we examined associative learning scores (i.e., faster for novel than for random). As can be seen in Table 2, the PerMag group exhibited less associative learning than the control, $t(135)=4.14$, $p<.001$, $d=.71$, and SocAnh groups, $t(132)=1.97$, $p<.05$, $d=.34$ [control vs. SocAnh: $t(131)=1.75$, $p=.08$, $d=.31$]. We then examined whether the groups differed in their learned irrelevance RT scores (i.e., faster for novel than for pre-exposed). Similar to the results for the associative learning effect, the PerMag group also exhibited a significantly smaller learned irrelevance score than the control, $t(135)=2.36$, $p<.05$, $d=.41$, and SocAnh groups, $t(132)=2.10$, $p<.05$, $d=.37$ [with no significant difference between the control and SocAnh groups, $t(131)=.10$, $p=.92$, $d=.02$]. In addition, as can be seen in Table 2, differences in RT in the PerMag group do not appear due to a speed-accuracy tradeoff as, if anything the PerMag group tended to have a smaller associative learning corrected hit rate score (i.e., PerMag group was *less* accurate for novel) than control, $t(135)=1.69$, $p=.09$, $d=.30$, and SocAnh groups, $t(127)=1.28$, $p=.20$, $d=.23$ (control vs. SocAnh: $p=.84$); similarly, the PerMag group had a significantly smaller learned irrelevance corrected hit rate score than control, $t(135)=2.19$, $p<.05$, $d=.38$, and SocAnh groups, $t(132)=2.35$, $p<.05$, $d=.42$ [control vs. SocAnh groups, $t(131)=.29$, $p=.77$].

We next examined whether group differences in associative learning and learned irrelevance effects were evident early within blocks (i.e., the first and second time that participants saw a predictive stimulus). For both associative learning and learned irrelevance RT scores, no group exhibited significant positive effects on the very first trial within blocks. However, by

the second presentation of the target within blocks, now both the control and the SocAnh groups exhibited significant associative learning (*p*s<.001, *d*s>1.21) and learned irrelevance (*p*s<.005, *d*s>.98) RT effects. Furthermore, on these second target presentations within blocks, the PerMag group exhibited significantly decreased associative learning and learned irrelevance RT effects than both control and SocAnh groups (*p*s<.05, *d*s>.34). Note that group differences between the PerMag and the other groups diminished on trials 3-5 for both associative learning and learned irrelevance RT scores (e.g., no significant group differences at the end of blocks). Again, these group differences in RT were not related to a speed-accuracy tradeoff as on corrected hit rates early within blocks the PerMag group exhibited smaller associative learning and learned irrelevance corrected hit rate effects than both the control and SocAnh groups. Hence, decreased associative learning and learned irrelevance effects were apparent early within blocks and further suggest problems in the PerMag group with initial processing and learning from novel stimuli.

Lastly, for all LIP scores, there were no significant differences between the PerMag groups with and without significant psychotic-like experiences, with if anything the PerMag group without psychotic-like experiences having the numerically smaller scores: associative learning RT: $t(67)=-.86$, $p=.39$, $d=.21$; associative learning corrected hit rate: $t(67)=-.50$, $p=.62$, $d=.13$; learned irrelevance RT score, $t(67)=-.09$, $p=.93$, $d=.02$; learned irrelevance corrected hit rate: $t(67)=-.41$, $p=.68$, $d=.10$. Hence, in contrast to the Weather Prediction Task, for the LIP there was no evidence that this task was especially impaired in those PerMag participants with significant psychotic-like experiences who have the greatest psychosis risk.

Finger Tapping Task

We examined each of the finger tapping scores in a 2 (hand type: dominant & non-dominant) X 3 (group: PerMag, control, SocAnh) repeated measures ANOVA. As can be seen in Table 3, there were no significant group effects for any of the scores: average number of taps: $F(2,199)=.41$, $p=.67$, $d=.13$; inter-tap interval: $F(2,199)=.29$, $p=.75$, $d=.11$; inter-tap interval variability: $F(2,199)=1.47$, $p=.23$, $d=.26$. However, there was a trend towards a hand type X group interaction for number of taps, $F(2,199)=3.02$, $p=.051$, $d=0.35$, as the SocAnh group tended to have a larger difference between dominant and non-dominant hands than the PerMag, $t(127)=2.49$, $p<.05$, $d=.44$, and control groups, $t(124)=1.86$, $p=.07$, $d=.33$ (with no difference between PerMag and control groups; $p=.79$, $d=.05$). Hence, overall, the PerMag group did not appear to be impaired on the finger tapping task.

Lastly, we examined whether the PerMag group with and without significant psychotic-like experiences differed in their finger tapping scores. There were no significant main effects of group for any of the indices (all *p*s>.57). There was a trend for a significant hand type X group interaction for number of taps, $F(1,67)=3.11$, $p=.08$, $d=.43$, as the PerMag group with significant psychotic-like experiences tended to have a smaller difference between hands, $M=.64$, $SD=.67$, than those without psychotic-like experiences, $M=.91$, $SD=.67$, but neither PerMag group differed significantly from controls, $p=.31$ and $p=.61$.[1]

Correlations between Striatum-Related Tasks

Next we examined whether striatum-related behavioral tasks were correlated with each other. On the Weather Prediction Task, as expected, better learning over time was associated with less use of the singleton strategy on the 4th quartile, $r(197)=-.41$, $p<.01$. On the Learned Irrelevance Paradigm, as expected, larger associative learning RT scores were associated with larger learned irrelevance RT scores, $r(197)=.67$, $p<.005$. However, the WPT scores were not related to LIP scores (all rs<.08). Further, measures from these two tasks were not associated with any Finger Tapping Task measure (all rs<.12). Hence, it appears that these three striatum-related tasks are largely unrelated to each other.

Associations with Current Mood

There were some expected group differences in current mood: both PerMag ($p<.05$) and SocAnh ($p=.06$) groups reported higher negative mood than the control group, with the SocAnh group reporting lower positive mood than PerMag ($p<.05$) and controls (p=.11). However, including any of these questionnaires did not alter group differences on the striatum-related behavioral tasks.

Discussion

In this study, there was evidence that psychosis risk was associated with two striatum-related tasks, the Weather Prediction Task and the Learned Irrelevance Task. Furthermore, there was evidence that PerMag participants with significant semi-structured interview-assessed psychotic-like experiences who have the greatest risk of psychotic disorder were especially impaired on the Weather Prediction task. However, psychosis risk was not clearly related to the Finger Tapping Task. In contrast, SocAnh was not associated with significant impairment on any of the three striatum-related tasks. The current psychosis risk results are not easily accounted for by risk for psychopathology in general as results were very different for the PerMag and the SocAnh groups. Overall, the current results potentially provide important new information about the behavioral correlates of psychosis risk.

Hence, associations between psychosis risk and the three striatum-related behavioral tasks were not uniform. Further, performance on the three striatum-related tasks were not significantly correlated. One possible explanation for this pattern of results is that these three tasks might reflect different striatal subregions. Again, there is consistent evidence for at least three striatal subregions: associative, limbic, and sensorimotor (Levitt et al., 2013; Lisman & Grace, 2005; Marchand et al., 2008; note however that research also indicates connections between these striatal subregions; Draganski et al., 2008). Although there is some evidence that the three tasks used in the current study may also be specifically related to certain subregions of the striatum (or to specific circuits that involve only these

[1]There is evidence that the SIPS item Suspiciousness predicts conversion to psychotic disorder (e.g., Cannon et al., 2008). Consistent with this, our rating of unusual thought content included both paranoid and non-paranoid unusual thought content. However, if we had instead also included the SIPS item Suspiciousness in determining whether people had at least a moderate level of psychotic-like experiences, then an additional 9 PerMag participants would have been included. Results with this expanded group (n=39) were very similar (e.g., within PerMag, those with psychotic-like experiences had decreased WPT learning compared to those without, n=30, $p < .01$; and there still were no significant differences between the PerMag groups on any of the Learned Irrelevance Task indices, ps > .35), with the one exception being that there were no longer any significant group differences in WPT strategy use.

subregions of the striatum within the larger circuit), it is important that future research replicate the findings of the current study using imaging methods in order to investigate whether these tasks are specifically related to certain subregions of the striatum. For the WPT, several brain imaging studies have reported strong associative, but not limbic or sensorimotor, striatum activation during performance of this task (e.g., Poldrack et al., 2001; Weickert et al., 2009). In contrast, the Learned Irrelevance Paradigm (Young et al., 2005) used in the current study is thought to be strongly related to the limbic striatum. Further, several imaging studies have found that finger tapping task performance is associated with activation only in the sensorimotor striatum (specifically the putamen; Delmaire et al., 2005; Moritz, Haughton, Cordes, Quigley, & Meyerand, 2000). Hence, one possible interpretation of the current results is that extremely elevated PerMag scores is associated with both associative and limbic striatum dysfunction and that, further, people in the PerMag group with especially heightened psychosis risk especially exhibit associative striatum dysfunction. Critically, there is still uncertainty whether these tasks do selectively activate only parts of the striatum, as for instance these tasks have not been examined together in the same brain imaging study. Therefore, an issue for future research is whether psychosis risk is especially related to dysfunction in a particular subregion of the striatum.

The possibility that psychosis risk is especially related to dysfunction in the associative striatum is consistent with some previous evidence. In particular, four recent PET imaging studies have found that psychosis risk is associated with increased dopamine synthesis capacity in the associative but not the limbic striatum (Egerton et al., 2013; Fusar-Poli et al., 2010; Howes et al., 2009; Howes et al., 2011). Overall, these results suggest that the functioning of the associative striatum might be especially important for understanding psychosis (Kegeles et al., 2010). However, it is important that future research investigate whether the Weather Prediction Task is specifically associated with impairment in the associative striatum in psychosis risk. Furthermore, while the associative striatum, in terms of regions of the striatum, has been arguably most strongly implicated in psychosis, other regions of the striatum have also been implicated in psychosis (e.g., Mittal et al., 2007).

Furthermore, on the Weather Prediction Task, the between-group effect size difference between PerMag participants with psychotic-like experiences and both control and SocAnh groups well exceeded conventional standards for a large effect. This is in contrast to a number of other studies that have often not found significant associations between psychosis risk questionnaires and behavioral task performance (Chun et al., 2013). One factor that might have contributed to finding a significant and large effect size is our combined use of both a psychometric high risk approach and semi-structured interviews assessing psychotic-like experiences to measure psychosis risk (Chapman et al., 1994; Cicero et al., 2014). To assess psychotic-like experiences with semi-structured interview, we used the more recently and widely used SIPS than the rating system used by Chapman et al. (1994) in their ten-year follow-up. An issue for future research would be to directly compare the degree of convergence between the SIPS and the Chapman et al. Wisconsin Manual for Assessing Psychotic-like Experiences (Chapman et al., 1980). In addition, another potentially important factor that might have contributed to finding a significant and large effect size is that the Weather Prediction Task might be especially related to the functioning of the associative striatum. Hence, the current results suggest that it is possible to find large effect

size associations between psychosis risk and behavioral task performance. Furthermore, the current results suggest that tasks like the Weather Prediction Task, potentially because they are related to associative striatum functioning, might have the potential to be especially useful as measures of psychosis risk detection.

One issue for future research is to further examine the nature of poor WPT performance in psychosis risk. Given previous evidence of increased dopamine in the associative striatum in people with psychosis risk, one possible interpretation is that the poorer learning in psychosis risk participants is due to an inverted-U relationship between striatal dopamine levels and task performance (e.g., Cools & D'Esposito, 2011). However, there is very limited direct evidence for an inverted-U relation between dopamine and Weather Prediction Task performance (Moody, Bookheimer, Vanek, & Knowlton, 2004). Another possibility is that poor performance on the Weather Prediction Task in psychosis risk reflects broader dysfunction in the cortico-striatum-pallido-thalamic circuit that involves the associative striatum. Consistent with this, there is evidence that psychosis risk is associated with impaired connectivity between the associative striatum and other regions, especially the prefrontal cortex (Dandash et al., 2014; Fornito et al., 2013). Similarly, it is possible that poor strategy use on the WPT in psychosis risk could reflect dysfunction in the prefrontal cortex. Another possibility is that dysfunction in some region outside of a cortico-striatum-pallido-thalamic circuit, such as the anterior cingulate cortex (Jung, Jang, Byun, An, & Kwon, 2010) is involved in poor Weather Prediction Task performance. Hence, a potentially important issue for future research would be to examine functional brain activation on the Weather Prediction Task in psychosis risk to further examine the nature of poor performance on this task.

Another issue for future research is to conclusively rule out any effects of antipsychotic medication on the WPT in psychosis risk. We assume that PerMag participants in this study were antipsychotic naïve, but a limitation of the current study is that we did not assess medication history. With rising antipsychotic medication use in children for non-psychotic disorders (Bobo et al., 2013), this should be explicitly examined in future research.

In the current study, there was also evidence that extremely elevated PerMag scores was associated with Learned Irrelevance Paradigm. This is consistent with these PerMag participants having problems processing the novelty and salience of stimuli. The current study is the first time that psychosis risk questionnaires have been associated with impaired performance on a latent inhibition task using a conventional extreme groups design, involving a relatively large number of psychosis risk participants, and examining both associative learning and learned irrelevance effects. Potentially, poor LIP in the PerMag group could reflect limbic striatum dysfunction that contributes to impaired novelty processing. However, although the Learned Irrelevance Paradigm is related to the limbic striatum, other parts of the brain (hippocampus & prefrontal cortex) also contribute to performance on these tasks (e.g., Murty, Ballard, Macduffie, Krebs, & Adcock, 2013; Young et al., 2005). Some issues for future PerMag research could be to measure functional brain activation on this task and also to examine other limbic striatum-related tasks to provide converging evidence for limbic striatum dysfunction.

However, although the PerMag group was impaired on the LIP, the PerMag group with especially heightened psychosis risk did not differ from other PerMag participants on the LIP. This suggests the possibility that poor performance on the LIP might reflect a more general increased risk for psychopathology in the PerMag group (e.g., increased risk of substance use disorders and mood disorders in PerMag; Chapman et al., 1994; Kwapil, Miller, Zinser, Chapman, & Chapman, 1997) but not be specifically related to increased risk of psychotic disorder. One issue for future research would be to compare LIP performance in a PerMag group versus other disorder risk groups. Another issue for future research is whether similar results would be found with other behavioral tasks associated with limbic striatum functioning.

In contrast to the WPT and LIP, the PerMag group did not exhibit impairment on the Finger Tapping Task. We did find a trend for a relationship between psychosis risk and one aspect of finger tapping as the PerMag group with psychotic-like experiences tended to have less of a difference between dominant and non-dominant hands on this task than the PerMag group without these symptoms, but neither group differed significantly from controls (in contrast, there was actually evidence for a greater difference between hands in the SocAnh group). Hence, overall, it does not appear that PerMag scores in this study were clearly related to the Finger Tapping Task. This could potentially suggest intact sensorimotor striatum functioning in the PerMag group. In contrast, one study did find that questionnaires assessing psychotic-like beliefs and experiences were associated with decreased tapping (Asai et al., 2009), however that study involved a very small unselected college student sample (n=50). Instead, the current results seem more consistent with three previous studies on people receiving clinical services at high risk for psychotic disorder, with none of these studies finding a significant overall association between psychosis risk and finger tapping (Guiliano et al., 2012). Therefore, it does not appear that psychosis risk is strongly associated with finger tapping performance. However, there is other evidence for motor functioning to be associated with psychosis risk. For example, motor symptoms have been found to predict conversion to psychotic disorder (e.g., Mittal & Walker, 2007). There is also some evidence for PerMag participants to be impaired on a line drawing task (e.g., Lenzenweger & Maher, 2002). The current study potentially suggests that it is possible that the motor measures previously associated with psychosis risk do not reflect sensorimotor striatum dysfunction. However, another potentially important issue is that the sensorimotor striatum itself might involve distinct subregions (e.g., the finding that the central putamen projects to premotor areas, whereas the dorsal putamen projects to motor areas; Draganski et al., 2008). Future research could examine whether only certain areas of the sensorimotor striatum are associated with psychosis risk, as well as whether other sensorimotor striatum measures are associated with psychosis risk.

In the current research, we have found that psychosis risk is differentially related to striatum-related tasks. Overall, we do not think the current results can easily be accounted for by task discriminating power or generalized poor task performance. First, the Finger Tapping Task was not associated with extreme PerMag scores and yet this task had greater true score variance than the Learned Irrelevance Task that was associated with extreme PerMag scores. Second, in terms of between-group difference discriminating power

(Melinder, Barch, Heydebrand, & Csernansky, 2005), the PerMag versus control group effect size was much larger for the Learned Irrelevance Paradigm associative learning effect than for the Weather Prediction Task fourth quartile strategy use. However, PerMag participants with significant psychotic-like experiences differed significantly from other PerMag participants only on WPT strategy use and not on LIP associative learning (with if anything better performance on the LIP). Finally, generalized poor performance in the PerMag group seems less likely given the lack of previous evidence for generalized poor task performance in this group (Chun et al., 2013). Furthermore, in the current study, PerMag participants with significant psychotic-like experiences did not exhibit poorer performance on every task compared to PerMag participants without these symptoms, as they exhibited numerically larger associative learning and learned irrelevance effects and also significantly higher non-dominant finger tapping scores. Hence, it is not clear that task discriminating power or generalized poor task performance can easily account for the current results. Future research should continue to examine the role of task discriminating power when examining whether psychosis risk is differentially associated with striatum-related tasks.

In contrast to the results for the psychosis risk group, we did not find that the SocAnh group significantly differed from controls on any of the striatum-related tasks. The current results suggest that striatal functioning may to some extent be intact in people with extremely elevated social anhedonia who are at increased risk for schizophrenia-spectrum disorders. The current results are also consistent with other evidence of intact performance in striatal-related measures in physical anhedonia in an at risk group (Padrao et al., 2013). However, the current results are not consistent with evidence that negative symptoms in schizophrenia, perhaps especially anhedonia, have been found to be associated with decreased limbic striatum activation (e.g., Dowd & Barch, 2012). It is possible that the limbic striatum is relatively intact in SocAnh but that because of deficits elsewhere in the brain (e.g., Gold et al., 2012) that in some instances processing of positive stimuli could be reduced, resulting in decreased limbic striatum activation. One issue for future research is whether other tasks and measures related to the limbic striatum rather than the LIP are in fact impaired in SocAnh. In addition, one limitation of the current study is that we did not collect interview ratings of negative symptoms in the current study and future research could examine whether presence of interview-rated negative symptoms predict task performance in people with extreme SocAnh scores.

Acknowledgments

This work was supported by National Institutes of Mental Health grant MH100359 and National Institute on Alcohol Abuse and Alcoholism grant AA019492.

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Table 1
Weather Prediction Task Accuracy Means (and Standard Deviations) for Each Group

	Group			
	PerMag (+)	**PerMag (-)**	**Control**	**SocAnh**
	Accuracy by Task Quartile			
1st Quartile	.63 (.12)	.59 (.12)	.59 (.13)	.58 (.12)
2nd Quartile	.68 (.12)	.64 (.14)	.69 (.14)	.66 (.14)
3rd Quartile	.70 (.15)	.68 (.17)	.72 (.18)	.68 (.15)
4th Quartile	.66 (.18)	.70 (.17)	.76 (.14)	.74 (.17)
	Summary Score			
Slope Estimate	.0002 (.0012)	.0055 (.0008)	.0082 (.0009)	.0076 (.0011)

Note. Slope estimate = rate of improvement in accuracy over the course of the task (using individual trial data in a multilevel logistic regression with data not grouped by quartile). PerMag (+) or (-) = with or without at least moderate psychotic-like experiences.

Table 2

Learned Irrelevance Paradigm Reaction Time and Corrected Hit Rate Means (and Standard Deviations) for Each Group

	Group		
	PerMag	**Control**	**SocAnh**
Reaction Time			
Block Type			
Random	426.40 (42.48)	432.04 (44.90)	423.45 (35.15)
Novel	398.22 (48.57)	370.89 (49.55)	379.46 (52.78)
Pre-exposed	404.18 (45.98)	391.39 (45.71)	399.21 (40.07)
Task Summary Scores			
Associative Learning	28.18 (40.37)	61.16 (52.18)	32.77 (39.14)
Learned Irrelevance	5.97 (31.61)	20.50 (40.05)	19.75 (43.51)
Corrected Hit Rate			
Block Type			
Random	.985 (.025)	.988 (.019)	.989 (.025)
Novel	.974 (.033)	.986 (.018)	.986 (.023)
Pre-exposed	.990 (.022)	.990 (.017)	.989 (.023)
Task Summary Scores			
Associative Learning	-.011 (.038)	-.003 (.034)	-.003 (.033)
Learned Irrelevance	-.016 (.035)	-.004 (.026)	-.003 (.026)

Note. Associative Learning=Random minus Novel Trial Type; Learned Irrelevance=Pre-exposed minus Novel Trial Type.

Table 3

Means (and Standard Deviations) for Finger Tapping Task Scores for Each Group

	Group		
Response Hand	**PerMag**	**Control**	**SocAnh**
	Average Number of Taps		
Dominant	7.15 (0.97)	7.38 (0.98)	7.47 (1.15)
Non-Dominant	6.37 (1.12)	6.55 (1.22)	6.37 (1.05)
	Inter-Tap Interval		
Dominant	139.49 (16.59)	136.68 (17.88)	135.64 (18.60)
Non-Dominant	158.46 (26.28)	156.18 (28.78)	158.39 (24.02)
	Inter-Tap Interval Variability		
Dominant	32.52 (12.80)	33.16 (13.52)	34.24 (11.86)
Non-Dominant	47.82 (29.88)	49.41 (30.27)	58.42 (43.47)