A TRANSCRANIAL MAGNETIC STIMULATION INVESTIGATION OF THE ROLE OF THE TEMPORAL PARIETAL JUNCTION IN SOCIAL INFLUENCE AND RISKY DEICISON MAKING

by

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LIST OF ABBREVIATIONS

Blood-oxygen-level-dependent	BOLD
Continuous Theta Burst Stimulation	cTBS
Computer Non-risky Influence	CNR
Computer Risky Influence	CR
Dorsolateral Prefrontal Cortex	DLPFC
Functional Magnetic Resonance Imaging	fMRI
No Influence	NS
Reaction Time	RT
Right Temporal Parietal Junction	rTPJ
Social Non-risky Influence	SNR
Social Risky Influence	SR
Temporal Parietal Junction	TPJ
Theory of Mind	TOM
Theta Burst Stimulation	TBS
Transcranial Magnetic Stimulation	TMS

ABSTRACT

A TRANSCRANIAL MAGNETIC STIMULATION INVESTIGATION OF THE ROLE OF THE TEMPORAL PARIETAL JUNCTION IN SOCIAL INFLUENCE AND RISKY DECISION MAKING

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The process by which individuals make decisions has important implications in a number of fields, such as economics and psychology. Several factors influence choice including characteristics of the decision itself, as well as environmental and individual factors. One source of deviation from typical decision-making is social influence, especially in decisions involving risk. The current study investigated the role of the rTPJ on social influence and risky decision-making using inhibitory cTBS. We hypothesized that susceptibility to social influence on risk-taking in an economic decision-making task would decrease following stimulation to the rTPJ, while risk-taking in the absence of social information should be unaffected. However, our results did not illustrate a significant relationship between stimulation and susceptibility to social influence, such that social influence increased risk-taking behavior. This may indicate that while the rTPJ is involved in decision-making in a social context, other brain regions are responsible for

the incorporation of social information into economic risk-taking. However, it is likely that computations of risk were inhibited through suppression of the nearby posterior parietal cortex. This is corroborated by trending effects of increased risk-taking and slower reaction times on the decision-making task, and the absence of deficits on a theory of mind task.

INTRODUCTION

The process by which individuals make decisions has important implications in a number of fields including economics and psychology. Faults and biases in decision-making processes can have devastating effects in areas of clinical significance (e.g. drug use) and economic significance (e.g. the amount and types of risk investors are willing to make in the market). A number of factors influence choice in these situations including environmental factors such as the context of the decisions (O'Brien & Ahmed, 2015; Li, Griffin, Yue, & Zhao, 2008), and individual factors, such as personality (McGhee, Ehrler, Buckhalt, & Phillips, 2012). Characteristics of the decision itself also influence decision-making, namely the amount of risk (Kuhnen & Knutson, 2005), the valence (Wolf, Wright, Kilford, Dolan, & Blakemore, 2013), and the value of the outcomes (Wright, Symmonds, & Dolan, 2013). Optimal decision-making processes generally seek to maximize utility, or the expected value of the outcomes, and thus choose whichever option has the highest expected value (i.e. the greatest monetary gain in the context of financial decision-making). However, certain characteristics of decisions can bias choice in a number of ways. One example of this being loss aversion, where aversion to negatively valenced options can lead to suboptimal decision-making such as increased risk-taking (Kahneman, & Tversky, 1984). Aversion to risk can also lead detriments in decision-making such as the valuing of risky prospects lower than their lowest outcome (Simonsohn, 2009).

Social Influence

One notable source of deviation from optimal decision-making is the influence of social factors such as the presence, attitudes, and choices of others (Bearden & Etzel, 1982). Humans have evolved to be social beings, resulting in strong effects of social influence (Dunabar & Shultz, 2007; Silk, 2007). Social factors can influence risk-taking behavior both indirectly, by changing the context of a decision, and directly, through providing information about another's beliefs pertaining to a decision. The effect of social context can be seen such that the mere presence of another individual can lead to greater risky driving behaviors than when alone (Gardner & Steinberg, 2005). This is further demonstrated in another study examining driving behaviors where it was found that when in the presence of an individual with a positive attitude towards risk (e.g. is more prone to take risks) these behaviors are further increased, especially in those with high susceptibility to peer pressure (Falk et al., 2014). The impact of other's choices on substance use behaviors is observed in studies conducted by Calafat et al. (2009) and Prinstein, Boergers, and Spirito (2001) where individuals abused drugs and alcohol more often when their friend networks also used drugs and alcohol compared to those with more prosocial networks. Social influences also play a role in economic risk-taking, demonstrated by Chung, Christopoulos, King-Casas, Ball, & Chiu (2015) where individuals were safer when presented with the safe choices of others, and more risky when presented with the risky choices of others in a decision between two lotteries.

These social influences play a role in our decisions above the role of nonsocial influences, such as those provided by technological sources (Carter, Bowling, Reeck, & Huettel, 2012), and engage different brain networks (Assaf, Kahn, Pearlson, Johnson, Yeshurun, Calhoun, & Hendler, 2009). Taken together, these studies provide evidence for a strong effect of others' choices on risky decision-making.

Decision Making

In an economic context, risk taking is defined as choosing an option with higher variance between the outcomes of a decision. This is seen where decisions with little to no risk have outcomes that are approximately equal (e.g. a lottery with a chance to win $1 or $2), while there is a greater difference between outcomes of high-risk decisions (e.g. a lottery with a chance to win $1 or $100). This definition can also be applied in a clinically relevant setting, such as an at-risk individual's decision to abuse drugs. In this situation, the outcomes of the decision to abuse drugs have a large variance such that the individual could become addicted to the substance (a largely negative outcome) or the person may never use the substance again (a neutral outcome). Most people are risk averse and will choose a less risky option when given the choice (Kahneman & Tversky, 1979), an effect that has been repeatedly demonstrated in recent literature (Symmonds, Wright, Bach, & Dolan, 2011; Wolf et al., 2013; Wright, et al., 2012). However levels of risk taking vary between individuals and situations. Differences in risk preference are impacted by both transient characteristics, such as the context in which the decision is made (e.g. in the presence of threat: O'Brien & Ahmed, 2015; or peers: Falk et al., 2014); as well as more stable characteristics, such as individual personality traits (McGhee et al., 2012), culture (Li, Griffin, Yue, & Zhao, 2013), and differences in genetics and neural response to risk (Cservenka & Nagel, 2012).

fMRI and Brain Stimulation

A number of areas in the brain implemented in decision-making processes have been studied using functional magnetic resonance imaging (fMRI), in particular the prefrontal and parietal cortices are heavily implicated in choice behavior. These regions contribute to decision-making in different ways, capturing differences in expected value, valence, skewness, and risk (Huettel, Stowe, Gordon, Warner, & Platt, 2006; Mohr, Biele, & Heekeren, 2010; Symmonds, Wright, Bach, & Dolan, 2011; Weber & Huettel, 2008; Wright, Symmonds, & Dolan, 2013). Specifically, the dorsolateral prefrontal cortex (DLPFC) has been implicated in the modulation of risk preference both in a nonsocial context (Gorini, Lucchiari, Russell-Edu. & Pravettoni, 2014; Cservenka & Nagel, 2012) and in the context of social influence (Suzuki, Jensen, Bossaerts, & O'Doherty, 2016). When this area of the brain is compromised, such as with psychopathology (Gorini, Lucchiari, Russell-Edu. & Pravettoni, 2014), or is developmentally immature, such as in adolescence (Rodrigo, Padron, Vega, Ferstl, 2014), this can have important implications for choice behavior.

Brain stimulation studies have overwhelmingly found effects of stimulation of the dorsolateral prefrontal cortex (DLPFC) on decision-making processes. These studies utilize techniques such as transcranial magnetic stimulation (TMS), including repetitive TMS (rTMS) and theta burst stimulation (TBS); as well as transcranial direct current stimulation (tDCS). The DLPFC is thought to influence decision-making and inhibit risk taking through its role in executive control and planning (Manes et al., 2002), and may even play a role in the effect of social influence in risk taking tasks (Suzuki, Jensen, Bossaerts, & O'Doherty, 2016). Modulation of this area has been demonstrated to affect risk-taking behavior using both TMS (Jeurissen, Sack, Roebroeck, Russ, & Pascual-Leone, 2014; Knoch, Gianotti, Pascual-Leone, Treyer, Regard, Hohmann, & Brugger, 2006) and transcranial direct current stimulation (tDCS; Fecteau, Knoch, Fregni, Sultani, Boggio, & Pascual-Leone, 2007; Gorini, Lucchiari, Russell-Edu. & Pravettoni, 2014; Minati, Campanha, Critchley, & Boggio, 2012; Nihonsugi, Ihara, & Haruno, 2015) techniques; demonstrating increases in risk taking when the DLPFC is stimulated using facilitatory stimulation (Knoch et al. 2006) and diminished risk taking when activity is suppressed by stimulation (Fecteau et al., 2007). However, brain regions underlying social influences on decision-making are less understood.

A meta-analysis conducted by Bzdok, Schilbach, Vogeley, Schneider, Laird, Langner, and Eickhoff (2012) demonstrated the involvement of a number of brain regions in social cognitions including the prefrontal cortex (PFC), superior temporal sulcus (STS) and temporoparietal junction (TPJ). Of these regions, the right temporoparietal junction (rTPJ) has been repeatedly demonstrated to be involved in theory of mind (TOM): the ability to attribute intentions and mental states to others (Gallagher, Happé, Brunswick, Fletcher, Frith, & Frith, 2000; Saxe & Kanwisher, 2003; Saxe, 2006; Costa et al., 2008; Dodell-Feder, Koster-Hale, Bedny, & Saxe, 2010; Young, Dodell-Feder, & Saxe, 2010; Hetu, Taschereau-Dumouchel, & Jackson, 2012). Theory of mind is especially important for determining the effect of social influence on decision making as it allows us to predict what the other agent believes is the best decision (informational influence) as well as how the agent will judge our decisions (normative influence), and factor these predictions into our own decision making (Deutsch & Gerard, 1955; Knoll, Magis-Weinberg, Speekenbrink, & Blakemore, 2015).

In studies employing economic decision making tasks, TPJ activation has been seen for decisions in a social context (Assaf, et al, 2009; Bhatt, Lohrenz, Camerer, & Montague, 2010); and patterns of activation in the region have been used to predict subsequent choice for these decisions (Carter, Bowling, Reeck, & Huettel, 2012). Involvement of the TPJ in more complex social decisions, such as those involving morality, is demonstrated in studies employing fMRI (Young, Cushman, Hauser, & Saxe, 2007) as well as brain stimulation techniques (Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010). Higher levels of blood-oxygen-level dependent (BOLD) activity within the rTPJ related to greater levels of risk taking are seen in individuals with less resistance to peer influence (Peake, Dishion, Stormshak, Moore, & Pfeifer, 2013). In addition, early adolescents, who are generally more susceptible to peer influences, show greater activation in this region than adults when presented with advice regarding a risky decision (Engelmann, Moore, Capra, & Berns, 2012). Although it remains possible that theory of mind is not necessary for the integration of others' choices on risky decision-making, this is unlikely as decreased performance on a decision-making task is seen in those with autism (a disorder with detriments to theory of mind processing) in a social context, but not in a nonsocial context (Robic, 2015). Together, these studies support an important role for the rTPJ, as well as theory of mind processing in the integration of social cognitions into decision-making.

THE CURRENT STUDY

The current study examined the mechanisms underlying the effects of social influence on risk and decision making through utilization of an economic decision-making task and continuous theta burst TMS (cTBS). Continuous theta burst stimulation was used to inhibit an area of the brain known to be involved in social cognition: the right temporal parietal junction (rTPJ). This area has been shown to be involved in theory of mind cognitions (TOM; Dodell-Feder, Koster-Hale, Bedny, & Saxe, 2010) such as mentalizing (Costa, Torriero, Oliveri, & Caltagirone, 2008), as well as decision-making in a social context (Carter, Bowling, Reeck, & Huettel, 2012; Carter & Huettel, 2013; Falk, et al., 2014). This area is also engaged in decisions involving morality (Jeurissen et al, 2014) and this involvement primarily regards the integration of others' mental states into judgments (Young, Camprodon, Hauser, Pascual-Leone, & Saxe, 2010).

To measure individual risk preferences and susceptibility to influence our experiment employed an economic risky decision-making task with the addition of influence information on some trials. Influence information included risky and safe influence information from both social and nonsocial sources. In line with current literature, we hypothesized that participants would be significantly risk-averse across conditions, choosing the riskier option less than 50% of the time. We also hypothesized that risky social information would influence participants to make more risky decisions, while safe social information would influence participants to make more safe decisions. Non-social information was also hypothesized to influence participant's decisions, however to a lesser degree than social influences, with safe non-social influence leading to a greater number of safe decisions and risky non-social influence leading to greater risky decisions.

Following inhibition of the rTPJ using cTBS, we hypothesized that effects of influence from social sources on risk taking should be decreased or eliminated due to the inhibition of integration of social information into decision-making within the rTPJ. In addition, reaction time to trials involving social information should be increased due to participant's decreased ability to engage in mentalizing processes. However, the effect of non-social influences on decision-making behavior and reaction times should not be affected. In addition, choice behavior in the absence of influence information should not be affected because the calculation and assessment of risk do not require engagement of theory of mind processing. Demonstration of this effect would allow for the conclusion that the rTPJ is integral for the cognitive processes involved in incorporating social information into decisions involving risk.

The current study also employed a false belief false photo task to measure theory of mind performance in order to verify that reduction in social influence was caused by a detriment to theory of mind processing. For this task, we hypothesized that, following cTBS to the rTPJ, response accuracy to theory of mind items would decrease and reaction times would increase compared to stimulation to a control site.

METHODS

Design

A within subjects design was used to examine how cTBS to the rTPJ impacts participant risk preference and susceptibility to social influence in an economic decision-making task. Each participant was presented with every condition during the task including social information indicating a risky choice, social information indicating a safe choice, non-social information indicating a risky choice, non-social information indicating a safe choice, and a control condition with no additional information. Participants experienced all these conditions during an experimental session following stimulation to the rTPJ and at a control session following stimulation to the vertex. Risk preference and susceptibility to influence were then compared between experimental and control stimulation conditions.

Participants

The sample was comprised of 22 participants (16 males, 6 females; *M* = 25.23 years, *SD* = 4.42), with recruitment through a roster of individuals from previous studies that indicated they would be open to being contacted about future research opportunities and received an anatomical structural scan. Two participants did not correctly follow directions for the false belief false photo task, so they were excluded from these analyses Participants were all right-handed and had normal or corrected-to-normal vision, and did not fall into any exclusion categories as determined through completion of appropriate screening for eligibility for TMS experiments, including use of medications known to reduce seizure thresholds. Rossi et al. (2009) provides a current list of these medications and other criteria. Participants were compensated for their participation through monetary compensation at a rate of $7.50 per half hour, plus an additional amount depending on their performance on the task (ranging between $2-24).

Transcranial Magnetic Stimulation

Participants completed two separate sessions where they underwent continuous theta burst stimulation (TBS). During one of these sessions the participant underwent stimulation to the rTPJ and during the other session the participant underwent stimulation to the vertex as a control condition. The location of individual participant's rTPJ was identified using coordinates from a meta-study conducted by Krall et al. (2014) examining the role of this region in attention and theory of mind. Standard Montreal Neurological Institute (MNI) coordinates for the region of the rTPJ found to be activated by false belief tasks (posterior rTPJ) were used (x = 54, y = -52, z = 26). The standard coordinates of the rTPJ from this study were then transformed to the participant's native anatomical space. This was accomplished using FMRIB's Linear Image Registration Tool (FLIRT) transform function (Jenkinson & Smith, 2001; Jenkinson, Bannister, Brady, & Smith, 2001) in FSL (version 6.0) using the inverse of the transformation matrix derived from the normalization of the individual's structural T-1 weighted MRI scan to the MNI template brain. This is similar to the localization methods used by Krall et al. (2016). For control stimulation, the vertex of the participant's scalp was used. The location of the vertex was determined similarly to Beam, Borckardt, Reeves and George (2009), by taking two measurements of the scalp and calculating the midpoint. First, the distance from left preaurical point to the right preaurical point was measured, then the distance from the nasion to the inion. The midpoint was then marked on the scalp to aid in targeting.

The order of these sessions was counterbalanced between participants. In order to decrease risk of seizure, there was a period of at least 24 hours between each stimulation session (Rossi et al., 2009). Brainsight Frameless Stereotaxic Software (Rogue Research, Montreal, Canada) was used to guide coil placement and deliver stimulation. A Magstim Rapid Magnetic Stimulation with a 70mm diameter figure-of-eight, air-cooled coil (Magstim, UK) was used to deliver cTBS to each participant at an intensity of 40% of machine output. Stimulation parameters were 200 bursts at 50Hz repeated for a 41 second chain of 600 pulses, similar to those used by Huang et al. (2005).

Procedure

Participants completed three laboratory sessions including one screening session and two stimulation sessions. When participants came into the lab for the initial screening they first gave informed consent in accordance with the George Mason University Human Subjects Review Board before beginning any additional parts of experiment. During the first session participants were screened in person for eligibility to undergo TMS by completing the Inclusion and Exclusion Criteria Checklist for TMS, and were provided an explanation of the risks involved in TMS and precautionary measures that must be taken prior to undergoing TMS. Pending confirmation of eligibility and consent participants had their picture taken and completed surveys pertaining to demographic information. Participants scheduled their first TMS session at the end of this initial session. The duration of this session was one hour.

At the beginning of both TMS sessions, participants completed the initial visit subject questionnaire to confirm they followed precautionary measures explained during the first session, including time sensitive conditions. In the first stimulation session, participants then chose one of four pictures of faces of the same gender drawn from the happy expressions portion of the lifespan database of adult facial stimuli (Minear & Park, 2004). The participant was told that these were pictures of past participants that have previously completed the study, and that they would be seeing some of the choices that participant made during the computerized task. To aid in the believability of this, participants were asked if they were willing to have their own answers used with future participants. The participant was also told that they would see choices of a computer on some trials, which would be represented by a cartoon picture of a computer. All participants completed both experimental and control stimulation conditions; with the order being randomized.

Prior to stimulation, participants were given an explanation of the decision-making and false belief/false photo tasks, and completed a short practice run before undergoing stimulation. Completion of instructions and practice tasks, as well as set up and stimulation lasted approximately 30 minutes. In the experimental simulation condition cTBS was applied to the rTPJ, with coil placement monitored using Brainsight neuronavigation software. Prior determination of the location of the rTPJ was done using standard coordinates transformed to the participant’s native anatomical space acquired using the individual's structural T-1 weighted MR image acquired prior to this study. Participants completing the control condition received simulation to the vertex of the head, determined through measurement from the nasion to the inion and from the left to the right preauricular. Following stimulation, the participant completed five runs of the economic decision-making task lasting for four minutes per run, as well as four runs of a false belief/false photo task lasting three minutes each, resulting in approximately 30 minutes for the behavioral tasks.

At the end of the second session participants scheduled a third session where they came into the lab to complete the condition they did not complete during their second session. Following completion of the third session, participants were compensated and debriefed.

Measures

Economic decision making task

Participants completed an economic decision-making paradigm measuring risk taking. In this task participants were presented with a choice between two lotteries with equal expected values and differing levels of risk: one safe lottery with low variance and one risky lottery with high variance. Individual propensity to take risks, or risk preference, was defined as the proportion of times they chose a riskier lottery over a safer: with riskier individuals choosing the risky lottery a greater proportion of times than less risky individuals. This paradigm is similar to others used to measure differences in risk taking and how these differences correspond to behavioral changes (O'Brien &

Ahmed, 2015; Wolf, et al. 2013; Wright, et al., 2012) and changes in activity within the brain (Engelmann et al., 2015; Wright, Symmonds, & Dolan, 2012).

Social influence

The influence of social factors on risk propensity was measured through the presentation of social information in some trials of the economic decision-making task. This information pertained to an individual thought to be a past participant in the study and included a picture of the individual as well as their choice on the trial, represented by an arrow indicating one of the lotteries. Nonsocial influence information was represented as a picture of a computer with an arrow pointing towards one of the lotteries. Participants were told that this represented the output of a decision algorithm taking into account the characteristics of the lotteries. Influence information indicating the individual or computer chose the riskier option is risky influence; while information indicating the individual or computer chose the less risky option is safe influence. Risk preference in both risky and safe social and nonsocial influence conditions was then compared to risk preference in the absence of influence.

False belief/false photo task

Participants completed a false belief/false photo task in order to measure theory of mind performance. This task is loosely based off the original Sally Anne test (Wimmer & Perner, 1983; Baron-Cohen, Leslie, & Frith, 1985) and is similar to other studies examining theory of mind (Happe, 1994; Costa et al, 2008). In this task participants were presented with a description of a situation pertaining either to an individual's belief or to an image (i.e. a photograph), following this the participant was presented with a statement that was either true or false depending on the previously described situation. Participants were asked to indicate whether this statement was true or false. Accuracy and reaction times of false belief items were analyzed to determine individual scores for TOM performance. The items used in this task include items drawn from a set of items shown to elicit theory of mind networks in the brain, including the temporal parietal junction (Dodell-Feder, Koster-Hale, Bedny, & Saxe, 2010); as well as slightly altered versions of these items to allow for a greater number of trials.

Analyses

IBM SPSS Statistics Version 19 was used compute all analyses. In order to determine if there was a significant difference in susceptibility to social influence or risk propensity following experimental and control conditions a 2 x 5 within-subjects ANOVA was conducted. An additional 2 x 5 within-subjects ANOVA was also run to determine if there were significant differences in reaction times in the decision-making task between influence and stimulation conditions. Two 2 x 2 within-subjects ANOVAs were run to determine if there were significant differences in theory of mind task performance for reaction time and accuracy scores following experimental and control stimulation conditions.

RESULTS

Risk Taking and Social Influence

Risk preference and response to influence

We hypothesized that participants would be significantly risk-averse. To test this hypothesis a one-sample t-test was conducted to determine if the percentage of risky decisions in each condition was significantly different than 50%. This hypothesis was supported, with participants choosing the riskier option significantly less than 50% of time across all conditions ($p < .05$).

We also hypothesized that social influence would change people's risk preferences, such that risky social influence would lead to greater risky decisions and safe social influence would lead to less risky decisions when compared to decisions in the absence of influence. We hypothesized that this effect of social influence should be decreased or eliminated by cTBS to the rTPJ compared to stimulation to the vertex, while the effect of non-social influences (such as choice information from a computer source) should not be affected. To test these hypotheses, we conducted a 2 x 5 within-subjects ANOVA with the factors stimulation type and influence type. A main effect of influence type was found, $F(4, 21) = 3.410$, $p = .012$. A simple test of within-subjects contrast was also conducted, revealing that risk preference under social risky influence was significantly higher than risk preference in the absence of influence in both stimulation conditions, $F(1, 21) = 8.142$, $p = .010$, while no other condition significantly differed from baseline. A main effect of stimulation type was trending, $F(1, 21) = 3.047$, $p = .091$), where participants had higher risk preference in the rTPJ condition than the vertex condition across influence conditions. Contrary to our hypothesis, there was no interaction effect between stimulation type and influence condition, $F(4, 21) = .371$, $p = .829$. See *Table **1*** for means and standard deviations of risk preference in each condition.

Table 1: Percentage of risky decisions across influence conditions following stimulation

Mean risk preference following stimulation (Percent risky decisions)

	Vertex	rTPJ	Average
Influence type	*M (SD)*	*M (SD)*	*M (SD)*
No influence	27.73 (23.13)	33.12 (23.82)	30.42 (22.66)
Social risky	32.94 (24.15)	38.90 (23.52)	35.92 (21.96)
Social safe	27.86 (21.01)	29.75 (23.32)	28.80 (21.35)
CPU risky	31.74 (21.42)	34.81 (22.62)	33.28 (18.75)
CPU safe	28.74 (21.05)	30.80 (27.03)	29.77 (23.40)
Average	29.51 (21.83)	33.92 (21.94)	31.71 (21.31)

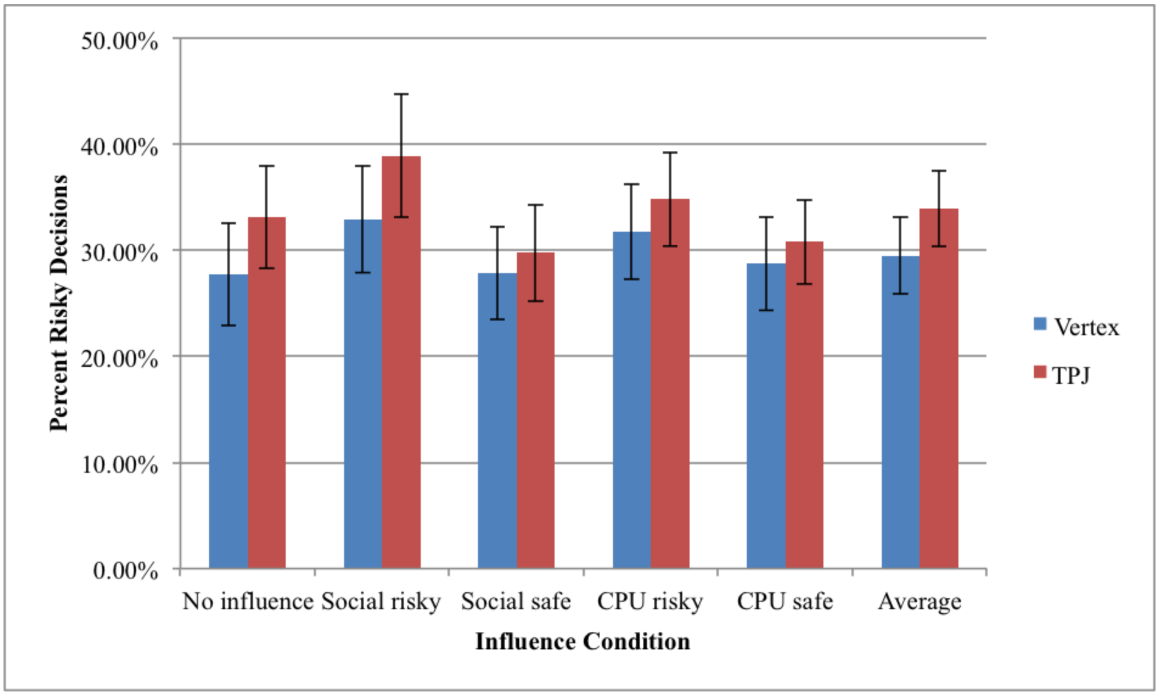


Figure 1: Group mean risk preference in the decision-making task for all influence conditions following stimulation. Error bars represent standard error.

Reaction times

We hypothesized that reaction times to social influence trials should be increased following cTBS to the rTPJ when compared to stimulation to the vertex, while reaction times to computer influence trials and trials without influence information should not change. A 2 x 5 within-subjects ANOVA was conducted to determine if there were significant differences in reaction times between influence and stimulation conditions. There was a trending main effect for stimulation type $F(1, 21) = 3.139$, $p = .091$ where participants were slower to respond following stimulation to the rTPJ compared to stimulation to the vertex. A significant main effect for influence was also found $F(4, 21) = 14.644$, $p < .001$. A simple contrast was conducted, revealing that participants responded faster to trials containing all types of influence than those containing no influence information ($p < .01$). See *Table **2*** for full reaction time data. There was no significant interaction effect between stimulation and influence conditions $F(4, 21) = .584$, $p = .675$.

Table 2: Reaction time for the decision-making task in seconds to all influence conditions following stimulation

Mean reaction time following stimulation (seconds)

	Vertex	rTPJ	Average
Influence type	*M (SD)*	*M (SD)*	*M (SD)*
No influence	0.73 (.20)	0.78 (.21)	0.76 (.18)
Social risky	0.67 (.21)	0.70 (.17)	0.68 (.17)
Social safe	0.61 (.16)	0.67 (.19)	0.64 (.17)
CPU risky	0.65 (.23)	0.72 (.21)	0.68 (.20)
CPU safe	0.64 (.19)	0.67 (.17)	0.65 (.16)
Average	0.66 (.19)	0.70 (.17)	0.68 (.17)

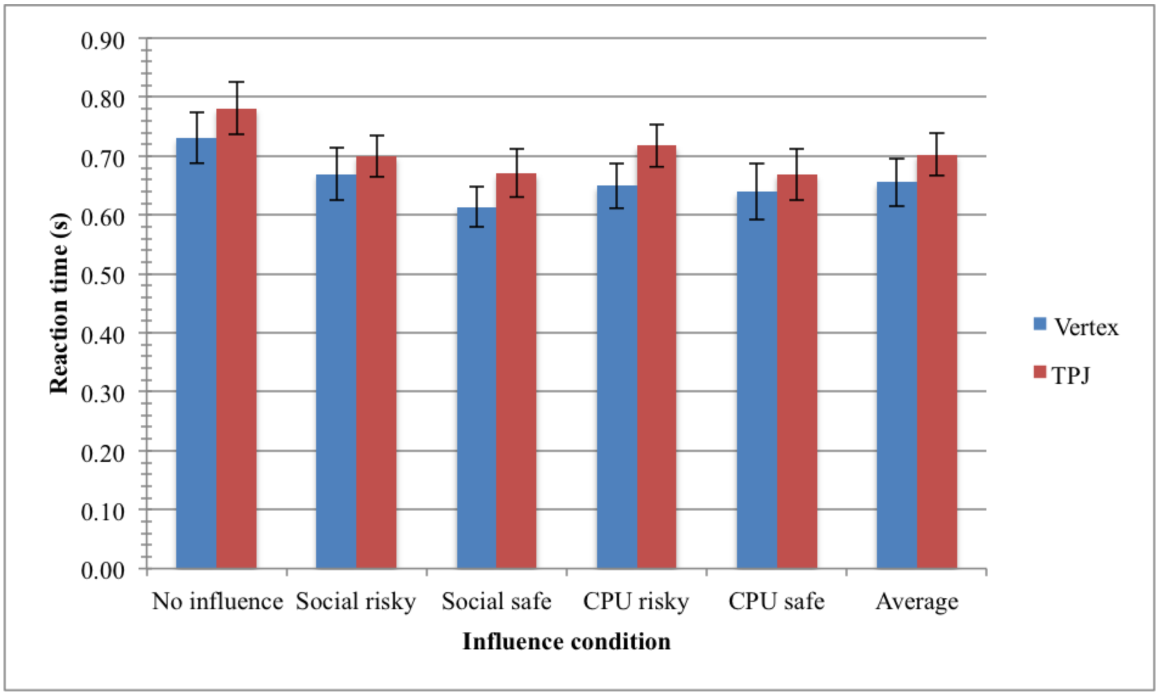


Figure 2: Group mean reaction time to the decision-making task in seconds for all influence conditions following stimulation. Error bars represent standard errors.

False Belief/False Photo Task

Accuracy

We hypothesized that stimulation to the rTPJ would decrease accuracy on theory of mind items, but not photo items on a false belief/false photo task. A 2 x 2 within-subjects ANOVA was conducted to determine if there were significant differences in accuracy between item and stimulation conditions. There was no significant main effect for stimulation type, $F(1, 19) = .219$, $p = .644$. There was a significant main effect for item type, $F(1, 19) = 8.000$, $p < .05$, with participants scoring significantly higher on photo items than theory of mind items (See *Table **3***). There was no significant interaction effect between item and stimulation conditions, $F(1, 19) = .905$, $p = .353$.

Table 3: Group mean accuracy for the false belief false photo task in percent correct following stimulation

Mean accuracy following stimulation (Percent correct)

	Vertex	rTPJ	Average
Item type	*M (SD)*	*M (SD)*	*M (SD)*
Theory of mind	61.25 (17.04)	61.25 (19.30)	61.25 (13.43)
Photo	69.06 (13.06)	65.94 (16.03)	67.50 (11.49)
Average	65.16 (14.02)	63.59 (16.51)	64.38 (11.48)

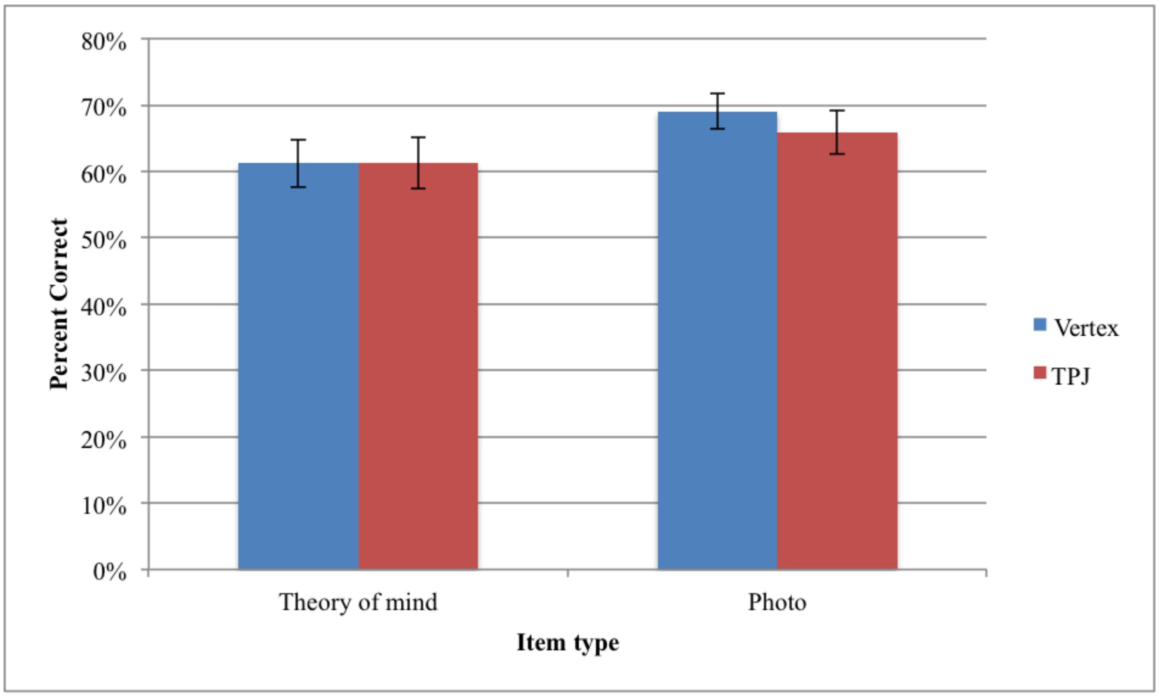


Figure 3: Group mean accuracy for the false belief false photo task following stimulation. Error bars represent standard errors.

Reaction times

We hypothesized that stimulation to the rTPJ would increase reaction times on theory of mind items, but not photo items on a false belief/false photo task. A 2 x 2 within-subjects ANOVA was conducted to determine if there were significant differences in reaction times between item and stimulation conditions. There was no significant main effect for item type $F(1, 19) = .219$, $p = .644$, or stimulation type $F(1,19) = .152$, $p = .701$. There was also no significant interaction effect between item and stimulation conditions $F(1,19) = .199$, $p = .660$. See *Table **4*** for full reaction time data.

Table 4: Group mean reaction time in seconds to the false belief false photo task following stimulation

Mean reaction time following stimulation (seconds)			
	Vertex	rTPJ	Average
Item type	*M (SD)*	*M (SD)*	*M (SD)*
Theory of mind	2.05 (.48)	2.10 (.42)	2.08 (.39)
Photo	2.05 (.47)	2.08 (.48)	2.07 (.40)
Average	2.05 (.47)	2.09 (.44)	2.07 (.39)

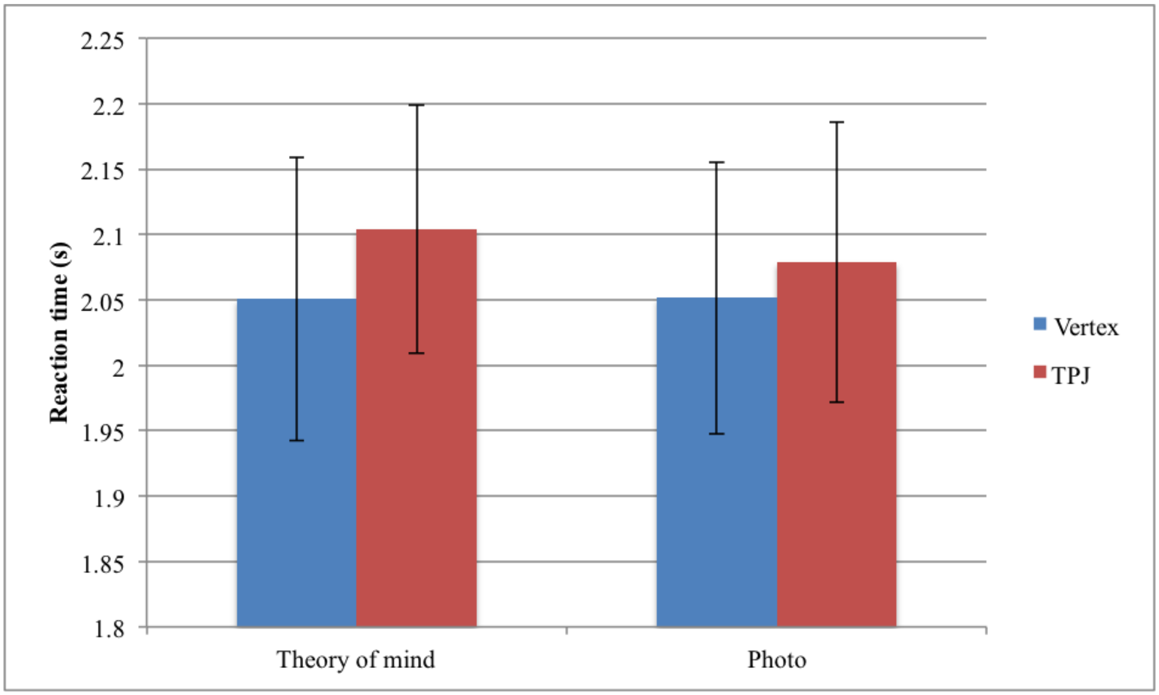


Figure 4: Group mean reaction time in seconds for the false belief false photo task following stimulation. Error bars represent standard errors.

DISCUSSION

The goal of the current study was to examine the neural mechanisms underlying social influence's effects on risk and decision-making through utilization of cTBS and an economic decision-making task.

Risk Taking and Social Influence

In line with current literature on risk-taking (Symmonds, et al, 2011; Wolf et al., 2013; Wright, et al., 2012), we hypothesized that participants would be significantly risk-averse, choosing the less risky option at a rate above chance. This hypothesis was supported, with risk aversion being seen across all influence and stimulation conditions (See *Table **1***).

We also hypothesized that risky social information would influence participants to make more risky decisions, while safe social information would influence participants to make more safe decisions. Non-social information was also hypothesized to influence participant's decisions in the same direction of the influence, however to a lesser degree. Conforming to our hypothesis, we found that risky social information elicited a significant effect on risk taking behavior, with participants making significantly more risky decisions in risky social influence trials than in trials without any additional information. However, social influence to be safe did not have a significant effect on risk preference. This finding demonstrates a powerful effect of social influence to increase risk-taking behavior. The capacity of social factors to increase risk-taking has been previously demonstrated in literature on driving behavior (Simons-Morton, et al., 2014) even in the absence of overt risk supportive attitudes (Falk, et al., 2014; Gardner & Steinberg, 2005). This effect has been shown to be especially salient in the developmental periods of adolescence, as well as young adulthood (Gardner & Steinberg, 2005; Knoll et al., 2015), an age range representing the majority of our sample.

We did not find a significant effect of computer influence on risk-taking behavior. This supports the importance of social factors on decision-making behavior above and beyond that from nonsocial sources (Carter, et al. 2012), such as influence information from technological sources (Chung, et al. 2015). This bias to attend to social stimuli is supported from an evolutionary standpoint, such that humans have evolved to be social beings (Dunabar & Shultz, 2007; Silk, 2007) in order to be successful in a largely social environment.

Effects of Transcranial Magnetic Stimulation

We hypothesized that inhibition of the rTPJ through cTBS would decrease the impact of social influence on decision-making processes, while non-social influences and decision-making in the absence of influence should not be affected. Contrary to our hypothesis, the effect of social influence to increase risk-taking behavior persisted following stimulation to both the rTPJ and the vertex. This may indicate that while the rTPJ is involved in decision-making in a social context (Assaf, et al, 2009; Bhatt, et al., 2010; Carter, et al., 2012), other brain regions such as the DLPFC (Engelmann, et al., 2012; Rodrigo, et al., 2014; Suzuki, et al., 2016) may be responsible for incorporating social information into economic risky decision-making and risk taking.

Although not reaching significance, there was a trending effect for stimulation across influence conditions where participants were riskier and slower following stimulation to the rTPJ compared to stimulation to the vertex. This effect may indicate that computations of probability and risk were inhibited through suppression of the nearby posterior parietal cortex, previously shown to be involved in processing risk (Huettel, et al., 2006; Mohr, Biele, & Heekeren, 2010; Symmonds, et al., 2011; Wright, et al., 2012). If stimulation in the current experiment resulted in suppression of posterior parietal cortex, than a diminished ability to engage in the computation of risk could be responsible for the observed increase in risk-taking behavior and reaction time to decisions.

In addition to the role of the rTPJ in theory of mind processing, the rTPJ has also been implicated in attentional shifting (Krall et al., 2015; Mitchell, 2008; Scholz, Triantafyllou, Whitfield-Gabrieli, Brown, & Saxe, 2009). Specifically suppression of the anterior rTPJ has been demonstrated to decrease performance in attentional reorienting tasks (Chang et al., 2012; Krall et al., 2016). Stimulation in the current study may have affected ability of participants to adequately pay attention to changes in the task, leading to poorer decision-making and greater risk taking. However, there were also no significant effects on performance on a false belief/false photo task on either belief or image items following stimulation to the rTPJ. The absence of a deficit on either of these items supports the argument that stimulation to the rTPJ was not successful in suppressing theory of mind processing or attentional reorienting, but instead suppressed processing of risk. If a deficit in attentional reorienting was responsible for increased risk-taking and increased response times, both theory of mind and photo items should have been affected. Instead, effects of stimulation only pertained to decision-making and risk.

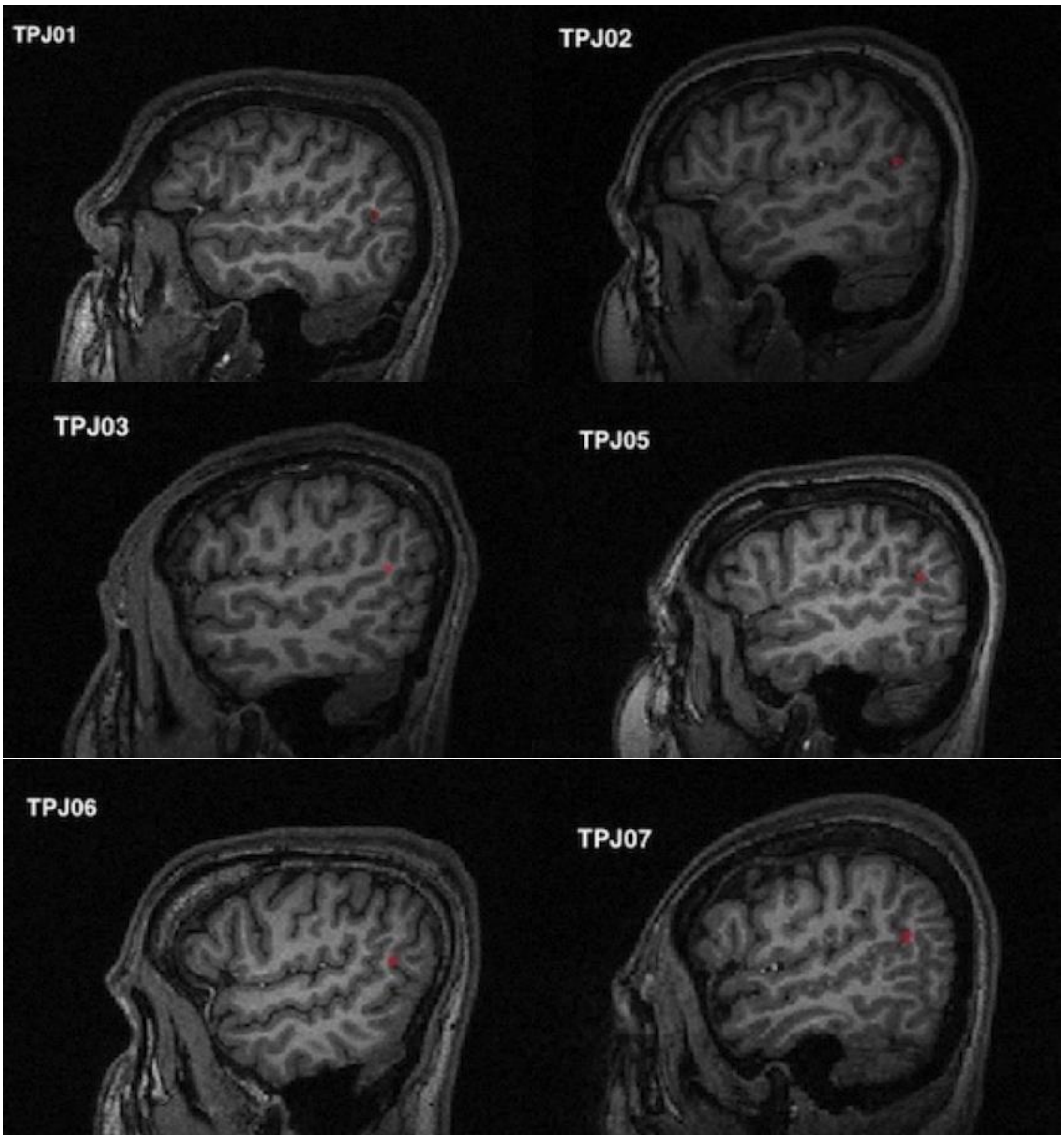
Conclusion

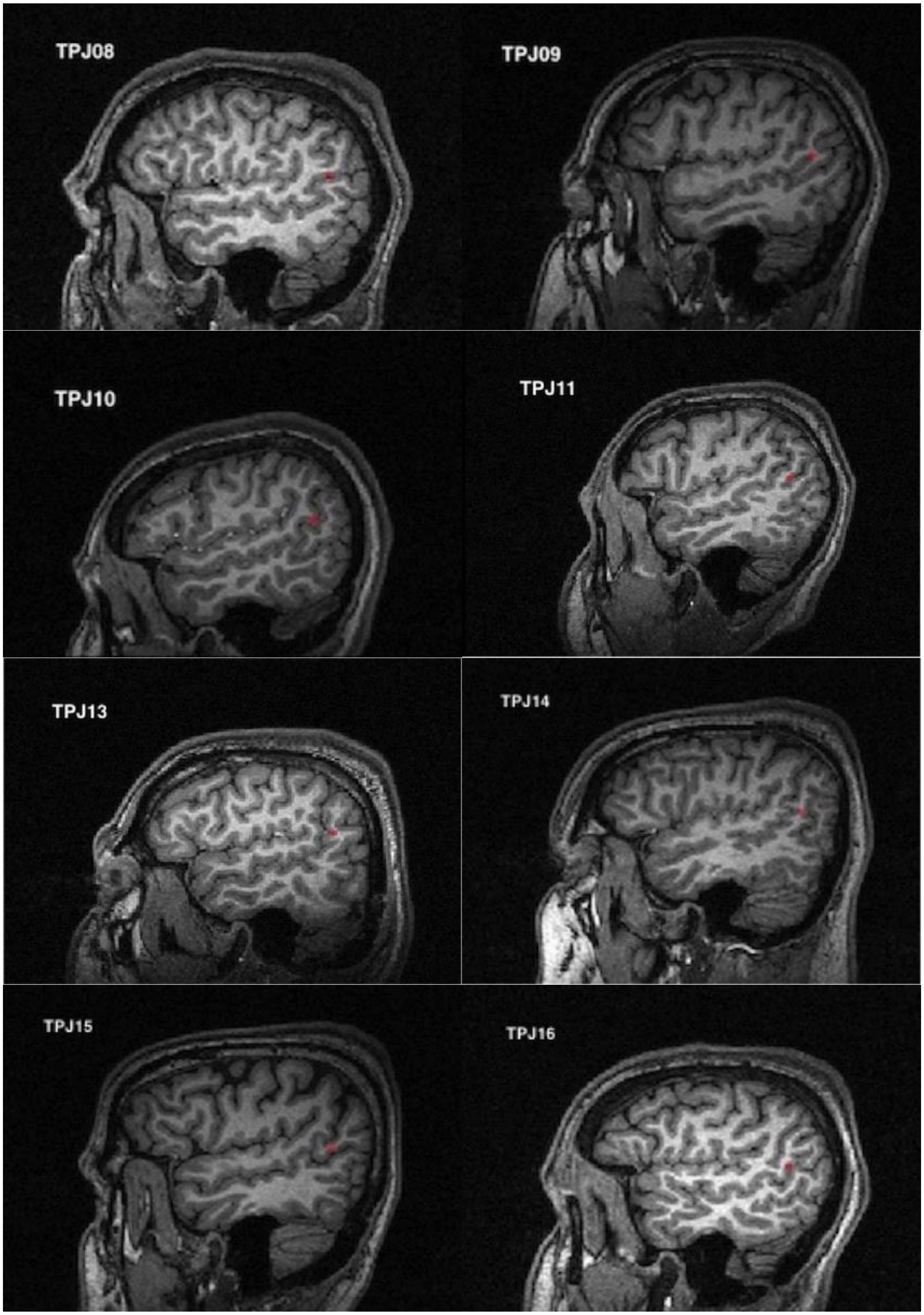
In sum, our results replicate previous findings on risk aversion demonstrating that when presented with a choice between two lotteries individuals generally choose the less risky option. In addition, economic risk-taking behavior is strongly influenced by social information to be risky, which can lead to increased risk preference, but not social influence to be safe. This finding is relevant both to economic risk-taking behaviors in a corporate environment, as well as health risk-taking behaviors such as engagement in drug abuse and risky driving, as risky behaviors in either of these realms can lead to a multitude of negative outcomes.

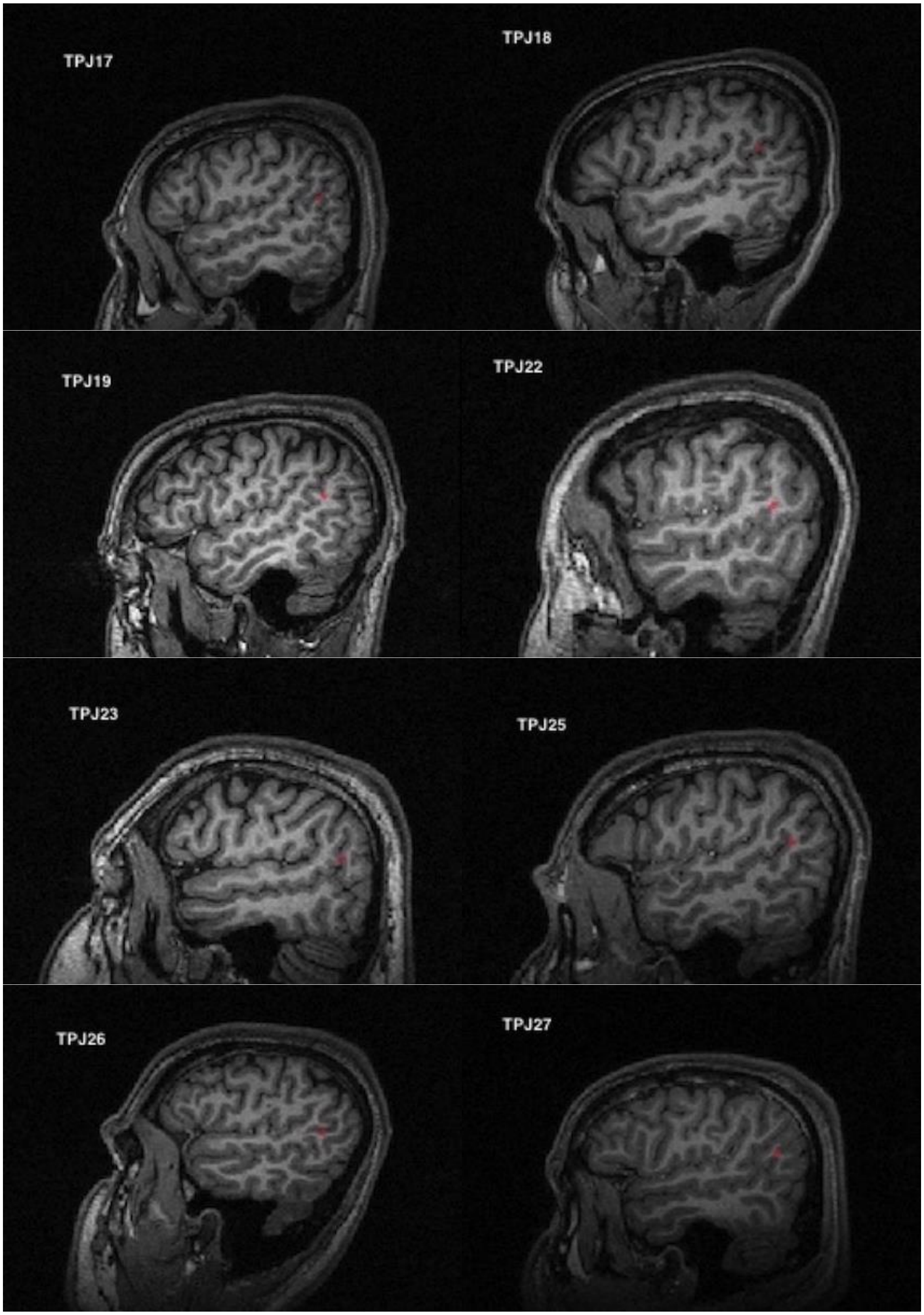
Contrary to our hypothesis, inhibitory stimulation to the rTPJ did not diminish effects of social influence to increase risk preference. This may indicate that other brain regions may be responsible for incorporating social information into economic risky decision-making and risk taking. However, it is instead likely that stimulation to the rTPJ affected nearby risk processing areas in the posterior parietal cortex. This is supported by findings of greater risk preference and slower response times to decision-making trials. The absence of stimulation effects for both belief and photo items in the false belief false/photo task also supports suppression of risk processing, rather than attentional processes, as detriments in attention would have resulted in decreased performance on both item types.

APPENDIX 1

TPJ Location



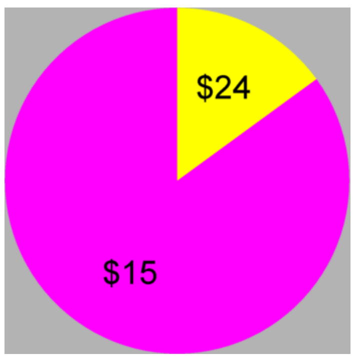

TPJ08
TPJ09
TPJ10
TPJ11
TPJ13
TPJ14
TPJ15
TPJ16

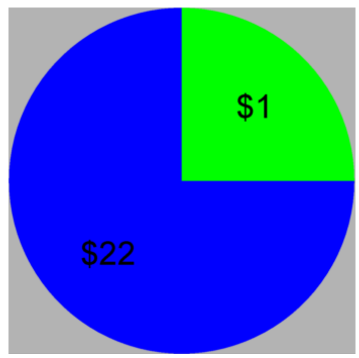

TPJ17
TPJ18
TPJ19
TPJ22
TPJ23
TPJ25
TPJ26
TPJ27

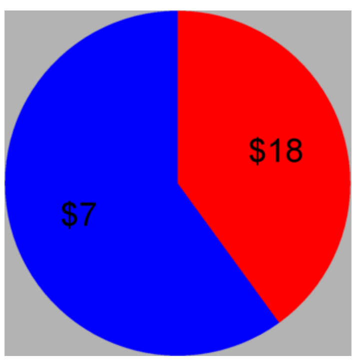
APPENDIX 2

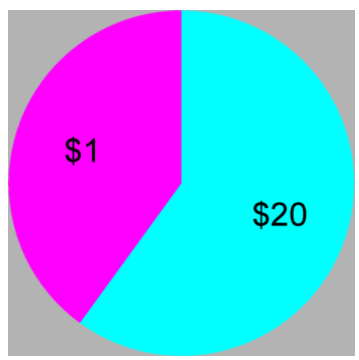
Example Lottery Pairs

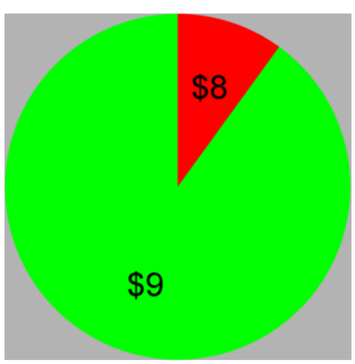
Safe Lottery | **Risky Lottery**

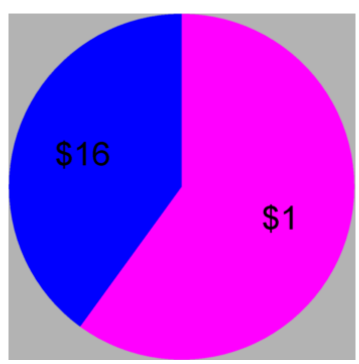












APPENDIX 3

False Belief False Photo Items

Type	Description Text	Original Text	Altered Text
Belief	Hopeful to catch a prize fish, George went fishing. That afternoon, he saw his fishing line bend over as if he had caught a big fish. Actually, George’s fishing pole had snagged a small tire	At the end of the fishing line, George sees a fish.	At the end of the fishing line, George sees a small tire.
Belief	When the class' science test was handed back, Shannon was mistakenly was given Adam's test. A large B was written on the front of Adam's test, but Shannon's actual grade was an A.	In reality, Shannon received an A on the exam.	In reality, Shannon received an B on the exam.
Belief	At night a bear broke into a cooler near a tent and drank the soda. Five hours later, the campers woke up and went to their cooler for breakfast.	In the cooler, the campers find no soda	In the cooler, the campers find the soda.
Belief	Amy walked to work today. When George woke up, he saw her car in the drive. Her room was quiet and dark. George knows that when Amy is sick, she lies down in a dark room.	In fact, Amy walked to work.	In fact, Amy is sick.
Belief	Sally and Greg called ahead of time to make a reservation for the back-country cabin. The park ranger forgot to write down the reservation and two other hikers got to the cabin first.	When the hikers arrive they see no one in their cabin.	When the hikers arrive they see Sally and Greg in their cabin.

Belief	A window wiper was commissioned by a CEO to wipe an entire building. He finished the right side, but his platform broke before he could do the left side. The next morning the CEO arrived with foreign investors.	The CEO comes to work and discovers that only the right side of the walls are cleaned.	The CEO comes to work and discovers that all of the walls are cleaned.
Belief	Susie parked her sports car in the driveway. In the middle of the night, Nathan moved her car into the garage to make room for his minivan. Susie woke up early in the morning.	Susie sees the minivan in the driveway.	Susie sees the sports car in the driveway.
Belief	The weather was so warm today that all the tulips in Pam's backyard suddenly bloomed. The tulips next to Pam's office still have not yet flowered, though. Pam has been at work all day.	Driving home after work, Pam supposes her tulips have not bloomed.	Driving home after work, Pam supposes her tulips have bloomed.
Belief	Jenny put her chocolate away in the cupboard. Then she went outside. Alan moved the chocolate from the cupboard into the fridge. Half an hour later, Jenny came back inside.	Jenny expects to find her chocolate in the cupboard.	Jenny expects to find her chocolate in the fridge.
Belief	Anne made lasagna in the blue dish. After Anne left, Ian came home and ate the lasagna. Then he filled the blue dish with spaghetti and replaced it in the fridge.	Anne thinks the blue dish contains spaghetti.	Anne thinks the blue dish contains lasagna.
Belief	Laura didn't have time to braid her horse’s mane before going to camp. While she was at camp, William brushed Laura's horse and braided the horse’s mane for her.	Laura returns assuming that her horse's hair isn't braided.	Laura returns assuming that her horse's hair is braided.
Belief	Larry chose a debated topic for his class paper due on Friday. The news on Thursday indicated that the debate had been solved, but Larry never read it.	When Larry writes his paper he thinks the debate has been solved.	When Larry writes his paper he does not think the debate has been solved.

Belief	When Lisa left Jacob, he was deep asleep on the beach. A few minutes later a wave woke him. Seeing Lisa was gone, Jacob decided to go swimming.	Lisa now believes that Jacob is sleeping.	Lisa now believes that Jacob is swimming
Belief	Expecting the game to be postponed because of the rain, the Garcia family took the subway home. The score was tied, 3-3. During their commute the rain stopped and the game soon ended with a score of 5-3.	The Garcia family arrives home believing the score is 5-3.	The Garcia family arrives home believing the score is 3-3.
Belief	John told Mary that he had lost his keys. The two of them searched the house with no luck. Then Mary went outside to look in the car. Suddenly John noticed his keys behind the sofa.	By the time Mary comes in, John doesn't know where his keys are	By the time Mary comes in, John knows where his keys are
Belief	The morning of high school dance Sarah placed her high heel shoes under her dress and then went shopping. That afternoon, her sister borrowed the shoes and later put them under Sarah's bed.	Sarah gets ready assuming her shoes are under the dress.	Sarah gets ready assuming her shoes are under the bed.
Photo	A large oak tree stood in front of City Hall from the time the building was built. Last year the tree fell down and was replaced by a stone fountain.	An antique drawing of City Hall shows a fountain in front.	An antique drawing of City Hall shows a large oak tree in front.
Photo	Accounts of the country's bustling economic success were recorded in both fiction and non-fiction books from the early 1900s. Soon after a horrible plague hit the country and the country was sent into an economic depression	Early 1900s novels portray the country as experiencing economic wealth.	Early 1900s novels portray the country as experiencing economic depression.

Photo	A long time ago, an explorer mapped a small island. Since then, the water levels rose and only a tiny part of the island is now left above water.	On the explorer's maps, the island appears to be mostly submerged.	On the explorer's maps, the island does not appear to be mostly submerged.
Photo	The family's old video tape recorded the daughter's first birthday party at their house in Chicago. Since then, the family sold their house and moved to San Francisco.	The video shows the family living in Chicago.	The video shows the family living in San Francisco.
Photo	Part of the garden is supposed to be reserved for the roses; it's labeled accordingly. Recently the garden has run wild, and dandelions have taken over the entire flower bed.	According to the label, these flowers are roses.	According to the label, these flowers are dandelions.
Photo	A biography describes the room as it was in 1965. Originally the walls were covered in dark wallpaper. By 1965 the paper had been stripped and replaced with cream paint.	The biography says that the room was light.	The biography says that the room was dark.
Photo	Sargent famously painted the south bank of the river in 1885. In 1910 a huge dam was built, flooding out the whole river basin, killing the old forests. Now the whole area is under water.	In the painting the south bank of the river is wooded.	In the painting the south bank of the river is under water.
Photo	A photograph was taken of an apple hanging on a tree branch. The film took half an hour to develop. In the meantime, a strong wind blew the apple to the ground.	The developed photograph shows the apple on the ground.	The developed photograph shows the apple on the tree branch.
Photo	Old maps of the islands near Titan are displayed in the Maritime museum. Erosion has since taken its toll, leaving only the three largest islands.	Near Titan today there are many islands.	Near Titan today there are three islands.

Photo	A volcano erupted on a Caribbean island three months ago. Barren lava rock is all that remains today. Satellite photographs show the island as it was before the eruption.	Today, the island is covered in lava rock.	Today, the island is not covered in lava rock.
Photo	When the picture was taken of the house, it was one story tall. Since then, the renovators added an additional story and a garage.	The house is currently one story.	The house is currently multiple stories.
Photo	The girl's middle school pictures showed her wearing a white blouse. Later, a red sock was accidentally washed with the blouse and the blouse turned pink.	Today the color of the blouse is white.	Today the color of the blouse is pink.
Photo	At the time a portrait was drawn of a young man, he had short brown hair and no facial hair. Now the man's hair is long and gray and so is his beard.	Today the length of the man's hair is long	Today the length of the man's hair is short.
Photo	A small leaf was placed on a wet clay flowerpot. When the pot was baked at high temperatures to harden the clay, the leaf crumbled, but its impression remained.	The actual leaf is not in tact.	The actual leaf is in tact.
Photo	A popular attraction in the park, pictured on many souvenirs, was a cliff face covered with ancient petroglyphs. Recently, the petroglyphs crumbled and scientists have not begun to restore them.	Today the petroglyphs can be seen on the souvenirs.	Today the petroglyphs can be seen on the cliff face.
Photo	When the photograph was taken, the boy in it was two meters away from the camera. The Eiffel tower is beside the boy in the photo; it was about 600 meters away.	In 'real life' the boy is bigger than the Eiffel tower	In 'real life' the boy is smaller than the Eiffel tower

APPENDIX 4

Inclusion and Exclusion Criteria Checklist for TMS

Subject ID: ____

Date of Screening: ______________________

Investigator Name: ______________________________________

Inclusion Criteria: (Must answer **yes** to all questions to be eligible for participation)

Are you older than 18 years of age?	Yes	No
Are you right handed?	Yes	No

Exclusion Criteria: (Must answer **no** to all questions to be eligible for participation)

Do you have any of the following:

History of, or active neurological problems including seizures?	Yes	No
History of psychoactive disorders, including mania, psychosis, or depression?	Yes	No
History of head injury with unconsciousness lasting more than 5 minutes?	Yes	No
History of stroke?	Yes	No
Previous brain surgery?	Yes	No
Other medical or neurological conditions?	Yes	No
Metallic hardware such as cardiac pacemakers, implantable medical pumps, ventriculo-peritoneal shunts, deep brain stimulators, or intracardiac lines?	Yes	No

History of tinnitus or hearing loss?	Yes	No
Are you taking any medications? (If yes, please discuss with investigator)	Yes	No

APPENDIX 5

Initial Visit Subject Questionnaire

ID# ______________________________

Date _____________________________

TMS Decision Making and Social Interaction

Initial Visit Subject Questionnaire

For the following questions please respond yes or no:

Y N Have you ever previously participated in any study involving TMS?

Y N Have you ever experienced a learning difficulty or been enrolled in special education classes? Please explain: ____

____

Y N Have you ever been diagnosed with or thought you might have an attention deficit? Please explain: ____

____

Y N Have you ever had a head injury? If yes was there a loss of consciousness? ______ If so, for how long? ____

Y N Have you ever had seizures, fainting spells, or migraines? Please explain: _______

____

Y N Have you ever been evaluated for a neurological disorder or possible neurological disorder? Please explain: ____

____

Y N Have you ever been evaluated for a psychological disorder or possible neurological disorder? Please explain: ____

____

Y N Have you been hospitalized for possible a psychological disorder in the last six months? Please explain: ____

____

Y N Have you been treated (or thought you needed treatment) for alcohol or drug abuse? Please explain: ____

____

For the following questions please circle Y or N and fill in the blanks:
Y N Did you sleep last night? If yes, how many hours? ___________________________
What is your average amount of sleep per night? _________________________________

Y N Do you drink caffeine? If yes, when was your last caffeinated beverage and how much did you drink? ____
How many drinks (cups of coffee or soda) do you drink per day on average? __________

Y N Have you consumed alcohol in the last 24 hours, if so how much? _____________
How many drinks per week on average? _______________________________________
How long have you been drinking alcohol? _____________________________________

Y N Do you smoke cigarettes, cigars, or pipes? If yes, for how many years have you smoked? ____
How many cigarettes, cigars, or pipes do you smoked per day? ____________________
How many cigarettes have you smoked in the past 24 hours? ______________________
When did you smoke your last cigarette (please note exact time)? __________________
Current time: _____________________
Y N Have you ever tried to quit smoking?
Y N Have you chewed nicotine gum or used the patch in the last 24 hours?

Demographic Questions:
What is your birthdate? (MM/DD/YYYY) ______________________________________

Of what ethnic/racial group do you consider yourself a member? Please circle any that apply:

Asian	Hispanic	White
African American	Native American	None

Other: ____

How many years of education have you had? ___________________________________
Any degrees held? ____
How many years of education did your parents complete?

Mother: ___________________________ Father: ____________________________

How many siblings do you have? ____

What is your first language? ____

Y N Were other languages used by your family?

List any languages you speak fluently: ______________________________________

List any languages you speak, but not fluently: _____________________________

Do you have any military/ROTC experience? If yes, please describe: ______________

____

Describe your current occupation: ____

____

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