The Social Contagion of Challenge-Seeking: Behavioural and Neural Correlates

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Declaration

‘I confirm that this is my own work and the use of all material from other sources has been properly and fully acknowledged.’

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Abstract

Despite having little economic utility, people are often motivated to seek challenges (i.e., proactively choosing to work on a more difficult task than an easier task). Although previous studies revealed various factors associated with challenge-seeking behaviours, there has been little research examining the potential effects of social cues. This thesis investigated whether observing other's challenge-seeking behaviours had a contagious effect. Participants' willingness to seek challenges were measured using a challenge-seeking task that differentiated challenge-seeking behaviours from similar concepts (such as mental effort or uncertainty resolution). In this task, participants' difficult word problem selections, compared to easier alternatives, were measured before and after experimental manipulations. This way, possible changes in participants' challenge preferences after observing challenge-seeker and challenge-avoider others were examined. Six behavioural experiments consistently showed that, while participants generally avoided challenging word problems, observing a challenge-seeker other increased their likelihood of choosing more challenging word problems. The observed shift in their challenge-seeking behaviour was not related to possible changes in participants' perceptions of word problem difficulty or self-confidence. Individual differences in achievement goals and trait intrinsic motivation levels contributed to participants' susceptibility to the contagious effect of observing others' challenge-seeking behaviours. However, environmental factors such as the agent likeability did not seem to play an important role in the behavioural change. Exploratory fMRI analyses revealed increased activations in the brain regions previously linked to social cognitive processing (inferior parietal gyrus, superior temporal gyrus, superior temporal gyrus, precuneus) and complex abstract (math-related) cognitive processing (angular gyrus). These results may be interpreted as the need for greater social processing when participants were seeking challenges whilst under the influence of challenge-seeker others. Overall, the current thesis indicated how challenge-seeking behaviours could be facilitated through social processes and discussed possible influences of individual and environmental factors in the social contagion of challenge-seeking.

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Chapter 1: General Introduction

Alex Honnold's ascend of the 900-meter-tall El Capitan without a rope or safety equipment, Wim Hof's ice endurance records achieved by climbing to Mount Kilimanjaro while wearing shorts, Rajveer Meena's memorization of 70,000 decimals of pi, Alan Turing's cracking of the complex cryptographic puzzles that significantly contributed to early computer development, and Andrew Wiles proving Fermat's Last Theorem after it remained unsolved for over 300 years—all stand as exemplary instances of humanity's pursuit of challenges. The inherent motivation to seek challenges urges us to venture into unknown territories, where the discovery of our limitless capabilities drives us toward reaching our fullest potential, fostering innovation, and pushing the boundaries of human achievement.

This dissertation focuses on the spread of challenge-seeking behaviours across individuals via social contagion—the unintentional transmission of one's behaviours, attitudes, and motives to people in their social environment (Levy & Nail, 1993). Given the pivotal role of challenge-seeking behaviour in skill attainment and mastery (Vygotsky, 1978), academic success (Porter et al., 2020), productivity (Li, 2015), and innovation (Luthans et al., 2013), investigating factors that could facilitate its promotion, such as social contagion, is of utmost importance. Based on the survey and social network data showing the social contagion of motivated behaviour across friends (Shin & Ryan, 2014; Li & Stone, 2018; McNabb et al., 2020), this dissertation aims to investigate whether individuals become more inclined to seek challenges following exposure to others seeking challenges, and if such a social contagion effect of challenge-seeking behaviour is subject to individual differences (e.g., observer's achievement goals, trait intrinsic motivation) and environmental factors (e.g., perceived likeability of the observed agent). Furthermore, it seeks to understand the neural mechanisms underlying the social contagion of challenge-seeking behaviour within the brain.

The current chapter gives the reader a background in challenge-seeking behaviour. It commences by defining what challenge-seeking is and how it differs from similar achievement concepts. Subsequently, it delves into the importance of challenge-seeking behaviour, outlining its benefits. Next, it reviews various motivation theories attempting to explain the reasons behind seeking challenges. Thereafter, neural underpinnings of challenge-seeking behaviour are explored. Finally, the individual differences and environmental factors influencing challenge-seeking behaviours are discussed. Among the environmental factors, social influences over challenge-seeking are examined, with a particular focus on the social contagion of challenge-seeking behaviour.

1.1. Challenge-Seeking Behaviour

Challenge-seeking is a manifestation of intrinsic motivation that refers to individuals' preference to seek out opportunities that would help them develop their current abilities and learn new skills (Harter, 1981; Ryan & Deci, 2000). Being intrinsically motivated refers to engagement in an activity for its inherent satisfaction and personal enjoyment rather than for gaining external rewards or due to external pressures (Ryan & Deci, 2000). Intrinsically motivated people intend to improve their skills and they are willing to spend their time and money on it (Wild et al., 1992; Marsden et al., 2015). Therefore, they actively seek opportunities to practice their skills.

In empirical research, challenge-seeking has been quantified as the preference to engage in difficult activities in which one can learn by making many mistakes, compared to easier activities that would involve minimal struggle or confusion that one can achieve without making many mistakes (Ames & Archer, 1988; Elliot & Dweck, 2013; Jagacinski et al., 2008; Lee & Kim, 2014; Malkiewich et al., 2016; Rege et al., 2021). One typical way of assessing challenge-seeking behaviour is to use math tasks. This approach is favoured because researchers can easily adjust the difficulty of math tasks and observe their participants' reactions to different levels of difficulty. Math problems (Kong et al., 2005; Jagacinski et al., 2008; Vassena et al., 2014; Porter et al., 2020), multiplication tasks, arithmetic rule-finding tasks (Lee & Kim, 2014), programming tasks (Malkiewich et al., 2016), and cognitive problems (for instance, those developed from Project Talent Questions, Flanagan, 1976) can be listed among such stimuli. There are also studies which preferred using non-mathematical tasks to study challenge-seeking. For instance, Pathania and colleagues (2019) created a video game in which participants were asked to catch as many asteroids as possible and throw them onto yellow targets that appeared on different sides of the screen. Researchers have increased the task difficulty by decreasing the asteroid's size and the time limit to catch the asteroid. A similar game-like task in which participants were asked to stop a stopwatch by pressing a button within the first 5 seconds of its start, was devised to study challenge-seeking behaviour in the absence of extrinsic rewards (Murayama et al., 2010;

Murayama et al., 2015; Sakaki et al., 2022). Anagram tasks (Lee & Reeve, 2017), visual discrimination (Boehler et al., 2011) and working-memory (Clay et al., 2022) tasks have also been used in previous research investigating challenge-seeking behaviour.

1.2. Differences from Similar Concepts

Challenge-seeking is closely linked to concepts such as persistence/ perseverance, resilience, effort, threat, and uncertainty resolution/curiosity. In certain scenarios, the expressions of these concepts might be indistinguishable from challenge-seeking behaviours. The section below attempts to explain how challenge-seeking differs from these concepts.

1.2.1. Challenge-Seeking vs Persistence/Perseverance

Persistence and perseverance are facets of the conscientiousness personality trait (Ventura & Shute, 2013), which are concerned with the ability to maintain engagement with a difficult task despite obstacles, setbacks, or difficulties (Porter et al., 2020). More specifically, persistence is about staying committed to a particular goal and working consistently towards achievement through effort, focus, and determination. Perseverance is defined as the continuance of effort and commitment to course towards a long-term goal (DiNapoli, 2023)

Individuals with high perseverance frequently exhibit challenge-seeking behaviours. For instance, they are less likely to run away from obstacles, change jobs in the face of adversity, or drop out of strict military training (Duckworth et al., 2007). While both challenge-seeking and persistence/perseverance are predictors of personal growth, they diverge in their approaches. Challenge-seeking focuses on actively seeking out challenges and embracing them as opportunities. Persistence and perseverance emphasise the ability to stay committed in the face of obstacles. Challenge-seeking is more proactive and forward-looking, whereas persistence and perseverance emphasize staying committed and determined.

In empirical research, perseverance and persistence are measured with long-term commitment and consistency of interests (DiNapoli, 2023), such as the amount of time voluntarily spent on a challenging task without giving up (Malkiewich et al., 2016) or duration of engagement in very difficult problems (Ventura & Shute, 2013; Porter et al., 2020). On the other hand, challenge-seeking is not concerned with long-term commitment or consistent effort to succeed in a difficult task. Instead, challenge-seeking is involved in the initial decision-making process of whether an individual chooses to undertake a challenge.

1.2.2. Challenge-Seeking vs Resilience

Resilience refers to the capacity to bounce back and recover after failures (Porter et al., 2020), and adapt to challenges (Oshio et al., 2018). Resilience is similar to persistence, but it is not a personality trait. Instead, resilience is a behavioural pattern associated with the personality trait of conscientiousness. Resilient individuals are flexible, emotionally strong, and able to adapt to challenging situations with a positive mindset (Campbell-Sills et al., 2006; Masten, 2018). Resilience is measured by the number of difficult puzzle selections (Kuhl & Blankenship, 1979) or correct responses after failure (Porter et al., 2020). For instance, a measure of resilience used by Mangels and colleagues (2006) was the academic performance of college students after being informed about the number of right and wrong answers they had in a previous test they took.

The similarity between resilience and challenge-seeking behaviour lies in both being dynamic and adaptive mastery-related concepts (Porter et al., 2020). Just as challenge-seekers engage in an active search for optimal challenges for skill improvement, resilient individuals adjust their strategies and perspectives in response to obstacles and, adapt to change by learning from setbacks and finding alternative paths to achieve their goals. Importantly, unlike challenge-seeking behaviour, resilience is a personality trait with an emphasis on recovery after adversity or a significant threat to the individual (Masten, 2018). Challenge-seeking, on the other hand, is an expression of intrinsic motivation (i.e., state), not a personality trait, and it applies to a wider scope of situations, not only limited to the behavioural tendency after failure.

1.2.3. Challenge-Seeking vs Effort

Effort specifies the intensity of mental or physical work that the organism should exert to achieve a goal (i.e., the amount of labour exerted by a person carrying a box) (Inzlicht et al., 2018). It is usually quantified as participants' degree of engagement in a tedious but skill-developing task (e.g., the amount of time spent on a challenging task) despite more enjoyable distractors (e.g., watching entertaining videos) (Galla et al., 2014). Previous empirical studies measured effort by manipulating the number of incongruent trials that required greater sustained attentional effort in a numerical Stroop task (Schmidt et al., 2012; Schouppe et al., 2014; Desender et al., 2016), by increasing the size of a list that participants should memorise to accurately detect items belonging to the list when asked later (Jansma et al., 2007), or by manipulating the number of spatial shifts of attention required to detect a peripherally appearing target rapidly changing location within a stream of distractors (Apps et al., 2015). Most of these studies have used a cue to signal the difficulty level of the upcoming trial to recruit mental preparation of effort (Boehler et al., 2011; Tian et al., 2011; Apps et al., 2015).

Challenge-seeking and effort are intertwined concepts that refer to different aspects of difficult task engagement. Effort is the physical or mental resource that an individual possesses, whereas challenge-seeking is an individual's incentive motivation to exert effort (Schmidt et al., 2012). Therefore, challenge-seeking occurs before the exertion of effort. Crucially, challenge-seeking focuses on the voluntary choice to engage in a difficult task. However, effort is not concerned with voluntary choice. Thus, in research studying effort, participants were not asked about their difficulty preferences; instead, they were informed about the difficulty of an upcoming task (Schouppe et al., 2014; Murayama et al., 2015). Furthermore, challenge-seeking behaviour is associated with positive feelings (Mierke et al., 2017) while effort is often considered aversive (see *effort discounting*, Vassena et al., 2014), possibly due to the nature of challenge-seeking behaviours which satisfies individuals' need for autonomy through voluntary choice.

1.2.4. Challenge-Seeking vs Uncertainty Resolution/Curiosity

Uncertainty resolution/curiosity refers to the desire to know, and it is operationalised as seeking information about events that do not have an extrinsic reward value to the individual (Berlyne, 1976; Ten et al., 2021; Murayama, 2022). According to the reward-learning framework of knowledge acquisition, information-seeking behaviour is activated if the expected reward value of missing information is sufficiently high for the individual (Murayama, 2022).

Curiosity-induced information-seeking and uncertainty resolution might take the shape of challenge-seeking behaviours, but the underlying motivations are different. While challenge-seeking is motivated by achievement drives; curiosity-induced information-seeking is motivated by the awareness of a knowledge gap (e.g., the solution of a difficult math problem); and uncertainty resolution is motivated by the desire to reduce the state of confusion, doubt, anxiety, and lack of confidence triggered by the awareness of the missing information (Berlyne, 1976; Kuhlthau, 1991). Imagine someone attempting to solve a math problem designed for the International Mathematical Olympiad. His motivation could stem from a desire to improve his math skills (challenge-seeking), to explore what an Olympiad-level math problem is like (curiosity), or to alleviate his anxiety, which is triggered by his low tolerance to missing information— the answer (uncertainty resolution). Unlike challenge-seeking, uncertainty resolution/curiosity focuses on predictability or an attempt to explain our environment (Redmond, 2015). Individuals may show challenge-seeking behaviours during the process of information-seeking, but a sense of achievement is not what they are after.

1.3. Importance of Challenge-Seeking Behaviour

The importance of challenge-seeking lies in its positive impact on skill attainment, academic success, productivity, and innovation.

Challenge-seeking is an essential aspect of skill attainment. According to the zone of proximal development introduced by Vygotsky (1978), learning occurs when learners attempt to exceed the limits of their skills. For instance, students who experimented with challenging coding techniques (e.g., using parameter blocks in a code, such as setting loops) developed greater coding abilities compared to those who used simpler techniques (e.g., writing the same code more than once) (Chase et al., 2021).

Having positive challenge-seeking norms is positively associated with achievement motivation and predictive of academic success (Blackwell et al., 2007; Yeager et al., 2019; Porter et al., 2020). Students who had positive challenge-seeking norms were less likely to attribute their failures to helplessness, such as questioning their own intelligence or doubting the fairness of the test (Blackwell et al., 2007). Instead, they were inclined to enrol in advanced math courses (Rege et al., 2021) and showed greater engagement in math tasks (Bettinger et al., 2018).

Challenge-seeking facilitates productivity. Pro-challenge-seeking culture in workplaces, which encourages new ideas, innovation, and adaptation to technological advancements, has been shown to increase employees' work ownership and stimulate creative thinking (Li, 2015). Sales representatives with high challenge-seeking tendencies for the sake of skill development employed desired work strategies and achieved a greater number of sales (Miao et al., 2007).

Challenge-seeking behaviour has also been associated with innovative behaviour (Luthans et al., 2013) and entrepreneurial characteristics (Mousavi et al., 2018). The link between innovation and challenge-seeking becomes particularly apparent in activities that demand creativity. For instance, when learning to compose music, learners engage in challenge-seeking behaviour to create innovative melodies using the question-and-answer technique. In this technique, the learner responds instructors' simpler melody by creating a more complex one (Soltani et al., 2012). Consequently, challenge-seeking becomes an important element of the innovation process.

1.4. Theories Explaining Why We Seek Challenges

A toddler engaging in symbolic play to test his understanding of his environment (Piaget, 2013) shows that humans start seeking challenges without expecting rewards at a very early age. Early theorists suggested that there must be an innate mechanism that drives challenge-seeking behaviour. Theories which attempt to understand what motivates one to seek challenges can be investigated under the following categories: theories that rely on (1) psychoanalytic approach/instincts, (2) the arousal level of the individual, (3) psychological needs/drives of the organism, and (4) the balance of skill and task difficulty (flow theory).

1.4.1. Instinct to Master

Earlier theories under the influence of Freud's theory of instincts claimed that humans have an innate biological inclination towards seeking challenges, or, in other words, an *instinct to master.* Hendrick (2007) who introduced the term argued that humans have an "*inborn drive to do and how to do".* Primordial pleasure is derived from the ability to alter and control the environment through basic sensory, motor, and intellectual functions (Hendrick, 2007). According to Hendrick, the instinct to master is best observed during skill acquisition. Skill acquisition takes place in three steps: (1) a reflex pattern is performed when the associated stimuli are present and the individual is physiologically able, (2) the pattern is repeated with different modifications, and finally (3) proficiency is gained when the pattern can be performed at will without further practice. Challenge-seeking is an essential aspect of the second stage, in which the individual repeats the pattern repeatedly to gain proficiency. This is when the instinct to master comes into play: It fuels challenge-seeking behaviour, which in turn leads to the exertion of effort (Hendrick, 2007). After sufficient effort, the skill acquisition cycle is completed.

1.4.2. The Arousal Theory of Motivation

The arousal theory of motivation argues that challenge-seeking behaviour is triggered by one's level of arousal. Individuals seek challenges when their arousal level falls below their threshold (Atkinson, 1957). This theory was supported by early research that employed physiological measures of arousal during challenge-seeking behaviours. Individuals who were hyperresponsive to environmental challenges (who showed excessive autonomic nervous system reactivity to challenges) often underestimated the difficulty of impossible-to-succeed tasks and preferred to engage in them (Ortega & Pipal, 1984). Importantly, these *challenge-seekers* showed elevated heart rates during challenging task involvement (Ortega & Pipal, 1984) and had increased levels of adrenaline and psychological distress when asked to be inactive for a period of time (Frankenhaeuser et al., 1980). Relaxation exercises that regulated their level of physiological arousal led to a relative decrease in their excessive, and perhaps unhealthy, challenge-seeking tendencies (Ortega & Pipal, 1984).

Although the arousal theory of motivation was supported by physiological findings, the (supposedly) linear relationship between arousal and achievement motivation failed to account for the debilitating consequences of overstimulation. When individuals experience arousal to the degree that it induces anxiety, they are more likely to exhibit avoidance behaviour (Rea, 2000). Furthermore, while some challenge-seeking behaviours might be motivated by arousal seeking, such as skydiving, the arousal theory of motivation cannot fully explain why individuals seek challenges across various scenarios, such as the motivation behind mountaineers climbing steep mountains. While mountaineering is considered a challenging activity, it requires a well-planned routine and discipline. Thrill-seeking behaviours are actively avoided due to their link to potential loss of control (Barlow et al., 2013).

1.4.3. Drive/Need Theories

Henry Murray was the first to introduce the term *need*. In his theory of personology, he argued that needs are dynamic entities that are triggered by certain internal and external conditions and cease once the individual takes action to change the initial conditions. He argued that psychogenic needs have properties similar to viscerogenic needs, such as the need for food and water (Murray, 1938). Individuals are motivated to maintain their biological and psychological needs in a state of homeostasis. When a biological or psychological need is aroused, balance is lost, and an unpleasant arousal state is experienced. The individual is motivated to address this need to reduce the unpleasant sensation (drive-reduction theory) and restore balance (Hull, 1943).

Drive and need theories claim that challenge-seeking behaviour is motivated by two psychogenic needs: the need for achievement and the need for competence. Just as a thirsty person would drink water to quench their thirst, individuals seek challenges to address their needs for achievement and competence.

Need for Achievement: The need for achievement (nAch) is the subcategory of the need for superiority in Murray's list of psychogenic needs. It is concerned with feelings of ambition and desire to succeed in a challenging activity (Murray, 1938). Murray's description of nAch is similar to the *esteem needs* introduced in Maslow's hierarchy of needs. Esteem needs are at tier four in the hierarchy; they are concerned with feelings of accomplishment, achievement, and mastery; and they are typically aroused after love and belonging needs are addressed (Maslow, 1943).

McClelland argues nAch is a learned need. It represents the strength of an individual's concern with achievement and provides an impulse towards excellence (McClelland et al., 1953, 1989; Atkinson, 1957). It could be satiated with the feeling of success, intensified with anticipation of failure (McClelland et al., 1949) and guided by self-attributed explicit achievement goals (McClelland et al., 1989). Individuals with strong nAch are likely to require activities with a greater risk of failure; while those with weaker nAch would likely prefer to minimise this risk (Atkinson, 1957).

nAch has usually been assessed using a Picture Story Exercise (PSE; McClelland et al., 1989) in which participants are requested to write a story based on the context of pictures featuring actors in different situations. These stories are then analysed by trained coders based on empirically validated elements from nAch motive categories. For instance, "adjectives that positively evaluate performances" is an element from nAch motive category (Winter, 2016). The PSE is a modernised and empirically validated (McClelland, 1953; Borsboom et al., 2004) version of the Thematic Apperception Test (TAT; Morgan & Murray, 1935).

Literature pointing to an association between the nAch and challenge-seeking behaviour suggests that higher nAch scores are linked to a preference for moderate challenges, longer work hours, and better college exam scores (Atkinson & Litwin, 1960). Women entrepreneurs with higher nAch scores believed in their ability to succeed in difficult tasks and were more motivated to take on challenging tasks and additional responsibilities compared to those with lower nAch (Lee, 1996). Furthermore, individuals with higher nAch scores had lower cortisol responses during challenging tasks compared to those with lower nAch scores (Schultheiss et al., 2014; Yang et al., 2015).

Need for Competence: According to Robert White (1959), the need for competence is an innate need to interact with and master the environment. The need for competence triggers directive and selective challenge-seeking behaviours. Facing challenges improves one's ability to master the environment effectively (White, 1959) and leads to the development of competence (also named *effectance*). Finally, perceived ability (*self-efficacy*), which is shaped by the individual's feeling of competence, satisfies one's innate need for competence. In White's words, "*doing well"* is not enough, *"doing better"* is necessary to meet the need for competence (White, 1959). Importantly, self-efficacy is influenced by task difficulty as well. There is a reverse U-shaped relationship between pleasure derived from successful task completion and task difficulty. When the task is too hard, even if it is achieved successfully, one may devalue the task due to the large amount of time and effort spent on its achievement. In this case, the emergence of embarrassment and frustration are more likely than the experience of high self-efficacy (Harter, 1978).

Self-determination theory (SDT) defines the need for competence in a similar fashion, as the motivation to feel a sense of mastery, that one can succeed and grow (Ryan & Deci, 2020). According to SDT, the need for competence is best satisfied when individuals face optimal challenges that enable them to develop their skills (Deci et al., 1996; Ryan & Deci, 2020). Optimal challenges encourage persistence, sustainment of effort, and heightened attention (Legault, 2017). On the other hand, if the challenges faced are too difficult and frequent; anxiety is experienced. If faced challenges are still too difficult but not as frequently, the feeling of worry emerges. If the challenges faced are too easy and frequent, boredom takes place. For instance, students who experienced non-optimal challenges at school (in the form of either over-challenge or under-challenge) reported high levels of boredom and lower career aspirations (Krannich et al., 2022). However, individuals who had challenging job demands (e.g., workload, time pressure, responsibility) had a satisfied need for competence (Olafsen & Frølund, 2018; Olafsen & Halvari, 2017). Therefore, challenge-seeking behaviours and a satisfied need for competence have a positive relationship (Mabbe et al., 2018).

1.4.4. Flow Theory

Flow theory argues that individuals are motivated to seek challenges to experience and maintain the pleasant sensation of the flow state (Tse et al., 2020). Flow is a state of extreme concentration characterised by an altered sense of time and an increased sense of control when one is deeply engaged in an activity. It occurs when the difficulty of the activity matches the skill level of the performer. The performer gets frustrated and anxious if the activity at hand is too difficult; and bored if it is too easy. In order to maintain the flow state, the performer seeks slightly more challenging activities every time a skill improvement is experienced (Csikszentmihalyi & Larson, 2014).

Previous research showed a positive relationship between the flow state and individuals' challenge-seeking tendencies. Individuals with a strong drive to seek and master challenges reported experiencing flow more frequently (Baumann & Scheffer, 2011). This relationship was especially evident for highly skilled individuals (Fullagar et al., 2013) and individual differences such as perceived task importance (Engeser & Rheinberg, 2008) moderated the relationship between flow experiences and challenge-seeking behaviours.

1.5. Neural Correlates of Challenge-Seeking

Challenge-seeking behaviour is suggested to be represented in the striatum (Murayama et al., 2010; Schouppe et al., 2014; Lee & Reeve, 2017; Sakaki et al., 2022) and anterior cingulate cortex (Kong et al., 2005; Vassena et al., 2014; Lee & Reeve, 2013; 2017).

1.5.1. Striatum and Challenge-Seeking Behaviour

The striatum is the largest input station in the basal ganglia, a region considered the heart of the reward network in the brain (Haber & Knutson, 2010). Dopaminergic projections from substantia nigra (SN) and ventral tegmental area (VTA) and connections to amygdala and thalamic regions (Graybiel et al., 1994; Delgado, 2007) make the striatum an important region that processes reward and valuation. Enhanced striatal activity has been associated with hedonic reactions (Lee & Kim, 2014) and reward processing, such as reward valence (Delgado, 2007), reward contingency (Kawagoe et al., 1998), reward preference (Hassani et al., 2001), and reward magnitude (Knutson et al., 2001).

Importantly, the striatum is not only linked to extrinsic rewards but also to intrinsic experiences. Increased striatal activation was linked to feelings of mastery and competence (Lee & Reeve, 2017) and correlated to growth mindset and perseverance (Myers et al., 2016). Individuals who engaged in challenging tasks without an expectation of reward showed an increased BOLD response in bilateral striatal regions (Murayama et al., 2010; Schouppe et al., 2014; Lee & Reeve, 2017; Sakaki et al., 2022).

The striatum has dorsal and ventral components. While both components receive dopaminergic input, they have slightly different functional connections. The dorsal striatum, comprising the caudate nucleus and the putamen, receives projections from the dorsolateral prefrontal cortex (DLPFC), premotor cortex, and frontal eye fields. The dorsal striatum is primarily associated with habit formation (Patterson & Knowlton, 2018), and reinforcement learning through extrinsic reward processing (Elliott et al., 2000; Knutson et al., 2001; Delgado et al., 2003). However, dorsal striatal activation was observed during intrinsically motivating tasks (Murayama et al., 2015), valued feedback (Tricomi et al., 2006), and achievement motivation (Mizuno et al., 2008) as well.

The ventral striatum, on the other hand, composed of nucleus accumbens (NAcc), receives input from orbitofrontal cortex (OFC), ventromedial and ventrolateral cortices, and amygdala (Lynd-Balta & Haber, 1994). Increased ventral striatum activation during high compared to low monetary reward anticipation (Elliot et al., 2000; Knutson et al., 2001), and tonically active neurons in the ventral striatum of macaque monkeys selectively responding to reward cues (Schultz et al., 1992) showed its involvement in extrinsic reward cue processing. Similar to its dorsal counterpart, the ventral striatum has also been linked to intrinsic experiences, such as mental effort valuation (Kang et al., 2009; Schmidt et al., 2012).

1.5.2. Anterior Cingulate Cortex and Challenge-Seeking Behaviour

Anterior cingulate cortex (ACC) has been traditionally viewed as a conflict monitoring and error detection region (Gehring & Knight, 2000; Cardinal et al., 2002; Bush et al., 2002). However, reports of increased ACC activation in decision conflict tasks (Ernst et al., 2004; Pochon et al., 2008), and preparation for demanding activities (Kong et al., 2005; Vassena et al., 2014) might indicate its involvement in challenge-seeking behaviour.

Decision conflict is the struggle one experiences when choosing between alternatives of similar perceived value (Pochon et al., 2008). Enhanced ACC activity was reported in response to instances of decision conflict, such as consideration of risky choices by assessing potential gains and losses (Ernst et al., 2004), and decisions to accept or reject monetary offers (Sanfey et al., 2003). Magno and colleagues (2006) showed that enhanced ACC activation tracked participants' preference for challenging task engagement. Using an attention-demanding search task with the goal of identifying the presence or absence of target stimuli, participants' choices to skip or stay in each trial were recorded. The decision to skip a demanding task was associated with the enhanced ACC activity.

ACC activation was also found to be related to the preparation phase of highly demanding activities. Enhanced activity in the ACC was observed prior to solving complex arithmetic problems (Kong et al., 2005; Vassena et al., 2014). Therefore, ACC might be involved in the recruitment of resources for an upcoming challenge.

1.6. Factors Influencing Challenge-Seeking Behaviours

The degree to which (or whether or not) challenge-seeking behaviours are performed can be influenced by certain individual differences and environmental variables. One's beliefs, values, and characteristic patterns of thoughts, feelings, and behaviours can be categorised as individual differences contributing to one's tendency to seek challenges. Provision of opportunities in which individuals can practice challenge-seeking, attitudes and behaviours of one's social network (friends, family and peers) can be categorised under the environmental factors shaping one's challenge-seeking tendencies. The current section is aimed at discussing the effects of individual and environmental factors by giving examples from early and recent empirical research for each category.

1.6.1. Individual Differences in Challenge-Seeking Behaviour

The most frequently reported individual differences in challenge-seeking behaviours can be examined under two categories: differences in (1) individuals' perceptions of self-concept and (2) the achievement goals individuals adopt.

Perceptions of Self-Concept: Individuals' perceptions of intelligence and ability concepts determine how they view challenges (Dweck & Leggett, 1988). Some believe that effort and practice can improve one's abilities (*growth mindset*) and intelligence (*incremental theory of intelligence*). These people consider challenges as opportunities for skill development and failures as part of the learning process. Thus, they greet them with a positive affect (Dweck & Leggett, 1988). Dweck, who has done pioneering work in the growth mindset research, quoted a student's words when discussing the growth mindset. The student said "I love a challenge" when she came across a problem she could not solve (Dweck, 2010).

On the other hand, some others believe that intelligence and competence are fixed and uncontrollable (*entity theory of intelligence*, *fixed mindset*). They believe humans are born with a certain set of skills which cannot be improved further. These individuals tend to attribute their failures to their inadequate intelligence (even if they succeeded in the same task a moment ago). After a mistake, their task performance declines significantly, and they engage in ineffective strategies such as cheating and distracting others from their mistake. For them, failure is associated with negative affect and humiliation. Therefore, failure is perceived as costly. Instead of risking failure, they prefer to avoid challenges and choose easier tasks with greater probability of success (Dweck & Leggett, 1988).

Therefore, having a growth mindset (in a way) shelters the individual against negative feelings associated with failures and encourages challenge-seeking for skill improvement. However, having a fixed mindset often renders the individual more sensitive to failures, and negative feelings associated with challenge-seeking.

Achievement Goals: Achievement goals are competence-related cognitive representations that guide individuals' behaviours (Nicholls, 1984). Early investigations in achievement motivation research led to the development of two distinct achievement goals: mastery and performance achievement goals (Nicholls, 1984; Dweck, 1986; Ames & Archer, 1988). Individuals' competence judgments play a grand role in the achievement goal they (likely) adopt (Nicholls, 1984; Dweck & Leggett, 1988). Those who judge their competence based on their own ability (self-referenced competence) are prone to adopting mastery achievement goals. These goals are associated with exploration and effort exertion to master something new and gain competence. In contrast, those who judge their ability with respect to the ability of others (other-referenced competence) often adopt performance achievement goals. These goals entail displaying high competence or hiding low competence (Dweck, 1986). Early achievement theorists (Nicholls, 1984; Dweck, 1986; Ames & Archer, 1988) and supporting research suggest that mastery achievement goals are associated with challenge-seeking behaviours while performance achievement goals are associated with challenge avoidance behaviours (Kuhl & Blankenship, 1979; Lee & Kim, 2014).

Individuals with mastery achievement goals welcome challenging tasks that require high effort and see them as opportunities for skill development (Nicholls, 1984; Ames & Archer, 1988). Research in mastery achievement goals led to the identification of two mastery achievement goal categories: (1) mastery approach and (2) mastery avoidance achievement goals (Elliot & McGregor, 2001). The difference between the two is that the mastery-avoidance goals' focal point of focus is the fear of incompetence, leaving a task un-mastered, or forgetting what is learnt. While previous research suggests that individuals with mastery approach achievement goals tend to engage in challenge-seeking behaviours for the sake of skill development, there have been no reported associations between mastery avoidance achievement goals and challenge-seeking behaviours (Jagacinski et al., 2008, Abercrombie et al., 2022).

Individuals who adopt performance achievement goals believe that high ability is mastering tasks that others fail, and doing so with minimum effort (Nicholls, 1984). They engage in challenge-seeking behaviours to demonstrate their skills to others and/or outperform others. If an activity requires them to spend more time and effort than others, they prefer not to engage in the task at all, due to the fear of humiliation (Nicholls, 1984; Mueller & Dweck, 1998). Jagacinski and colleagues (2008) showed that, during an experimentally induced performance achievement goal state, those who had less perceived ability were less likely to choose difficult math problems compared to those with more confidence. Later work separating the performance achievement goals into approach and avoidance categories (Elliot & Harackiewicz, 1996) showed that those who aimed to outperform others (performance approach achievement goals) sought moderately difficult challenges compared to those who aimed not to perform worse than others (performance avoidance achievement goals).

1.6.2. The Effects of Environmental Factors on Challenge-Seeking Behaviour

Optimal Difficulty: The discrepancy-reduction model (Dunlosky & Hertzog, 1998) suggests that dedicating more time to mastering the (subjectively) most difficult tasks is the optimal route to reduce the number of unknown elements and the amount of ambiguity to a minimum. It makes sense in theory, but in practice, seeking very difficult challenges may lead to the development of negative judgments about the learning process in general, and might reduce the probability of seeking challenges in the future (Metcalfe, 2009). Instead, working on difficult tasks is preferred only if engagement facilitates learning (Ten et al., 2021). Therefore, individuals are more inclined to go for optimal challenges that promote learning through a sense of competence (Ryan & Deci, 2000) and task achievement (McClelland et al., 1949; Csikszentmihalyi & Larson, 2014)

Vygotsky (1978) proposed that what an individual can do alone and with the guidance of a more knowledgeable other are different stages of learning. According to this account, independent activity shows the abilities in an individual's skill set whilst activity with the guidance of others shows the ability "in maturation" stage (Vygotsky, 1978). Importantly, the difference between these two stages is the skills within the individual's reach, or in *the zone of proximal development*. Imagine a kid having difficulty solving a math problem. This kid is more likely to learn how to solve the problem if the teacher teaches the solution using a similar problem as an example, compared to using an advanced math problem as an example to teach (Vygotsky, 1978).

Similarly, Walker (1980), in his hedgehog theory of behaviour, suggested that activities are preferred based on their subjective complexity. Consistently, Csikszentmihalyi suggested that the flow state is experienced only when the individual's skill level matches the demands of the activity of interest (Csikszentmihalyi & Larson, 2014). With repeated encounters, a complex action gets easier, in other words, it gets closer to the optimal complexity level of the individual. At the optimal complexity, the activity is perceived as enjoyable. Importantly, repeated exposures also cause the activity with optimal complexity to become too easy and boring for the individual. When this happens, the individual is motivated to move on to new challenges (Walker, 1980; Csikszentmihalyi & Larson, 2014). An over-challenged learner might lose interest, lose self-esteem, and avoid challenges in the future. These outcomes can even impact the career decisions of the individual (Krannich et al., 2022).

The application of artificial intelligence techniques that personalise difficulty setting has provided evidence to support the importance of optimal difficulty seeking in task engagement and learning (for a review, see Oudeyer et al., 2016). For instance, Clement and colleagues (2013) developed a multi-armed bandit algorithm that monitors individuals' learning progress and dynamically switches between introducing new exercises and focusing on the ones that maximize learners' progress. Similarly, a two-agent tutoring system proposed by Beuls and Loeckx (2015) has been predicted to keep students in the state of flow while having them engage in the learning process actively. In this system, a student model was updated after each interaction with the real student, so that it could predict gaps or inconsistencies in a real student's knowledge and provide exercises that matched the skill level of the student.

Social Factors: Perception of social cues is another important factor influencing individuals' challenge-seeking tendencies. Previous studies investigating the effect of social cues on challenge-seeking behaviour usually focused on social support. Challenge-seeking culture of the learning environment (Kashdan & Yuen, 2007) and achievement-related beliefs of parents (Katkovsky et al., 1964) and teachers (Frenzel et al., 2019) were found to be indicative of the facilitation or inhibition of individuals' challenge-seeking tendencies. For example, the use of coercion and intimidation techniques during teaching (Ryan & Deci, 2000) and perceiving the teacher as threatening (Peters, 1978) led to greater challenge avoidance. However, in learning environments that valued challenge-seeking (Kashdan & Yuen, 2007), and if teachers acknowledged their students' inner psychological needs, offered them choices and provided rationale during teaching sessions (i.e. autonomy support) challenge-seeking was fostered (Baten et al., 2020).

The studies investigating the effect of perception and interpretation of social cues on challenge-seeking behaviours are limited. (Baten et al., 2020; Reinboth et al., 2004). This lack of empirical evidence is rather surprising, as both the self-determination theory and the theory of need for achievement indicated the importance of social context (Deci & Ryan, 1985; McClelland et al., 1953; Bandura, 1977) for intrinsic motivation. The current thesis aims to investigate the effects of social cues on challenge-seeking behaviours by studying the social contagion of challenge-seeking tendencies. Social contagion is the unintentional transmission of one's behaviours, attitudes, and motives to those in their social environment (Levy & Nail, 1993). Although the social contagion of motivation has been previously demonstrated (Wild & Enzle, 2002), the research question of whether challenge-seeking tendencies are also contagious has not been empirically studied yet.

1.7. Social Contagion of Challenge-Seeking

In self-efficacy theory, Bandura claimed that motivation can be transmitted through vicarious learning from observing someone showing interest towards an activity (Bandura, 1977). One's perceptions of the motivational state of the other person can lead the observer to form expectations about the quality of involvement that would likely be experienced (such as interest and pleasure associated with an activity), thus giving rise to the contagion effect (Wild et al., 1992). Intrinsic motivation and its manifestations (such as task engagement and enjoyment) and achievement-related goals and beliefs have been demonstrated to be socially transmitted across friends, family or strangers, in both in-person and online settings (for a review, see Wild & Enzle, 2002). The social contagion of challenge-seeking behaviour has yet to be examined.

The social contagion of intrinsic motivation and achievement-related beliefs and behaviours have been explored between close friends (Krishen, 2013) and family (Katkovsky et al., 1964; Eccles et al., 1993) and empirically studied across various settings, from the gym (Scarapicchia et. al., 2013) to the classroom (for a review, see Burgess et al., 2020). For instance, a similar level of work engagement was observed between couples (Bakker et al., 2005) and between coworkers in frequent interaction (Bakker & Xanthopoulou, 2009). Students who spent time with intrinsically motivated students (Altermatt & Pomerantz, 2003; Krishen, 2013) or teachers (Wild et al., 1992; Frenzel et al., 2019) showed elevated intrinsic motivation and adopted similar academic achievement goals (Bargh et al., 2001; Shin & Ryan, 2014; Gremmen et al., 2017; King & Mendoza, 2020; Mendoza & King, 2022).

Importantly, more recent studies indicated that it does not take too long for the social contagion effect to work its magic. Early social contagion research was focused on changes in behaviour across friends and family, in other words, between individuals who usually spend a lot of time together for a long period, but recent work indicated that individuals could be susceptible to the contagious motivation of others they have just met (Friedman et al., 2010; Scarapicchia et. al., 2013). Inactive women spent more time exercising, and they were more likely to continue exercising when paired with intrinsically motivated strangers who reported enjoyment in exercising, compared to inactive women who were there only for the participation fee. (Scarapicchia et. al., 2013). Participants who observed strangers showing intrinsic motivation towards a Nintendo game, spent more time playing the game during the free choice session, compared to the participants who observed extrinsically motivated strangers (Friedman et al., 2010). In fact, more recent work by Suzuki and colleagues (2016) demonstrated that motivation contagion can occur in online encounters as well. They found that risk preferences could be transferred by simply observing a recording of an individual gambling in a risk-averse or risk-seeking manner.

Note that social contagion is distinct from conformity. Conformity is a change in behaviour towards that of a group of people due to social pressures (normative conformity) (Zaki et. al., 2011; Gommans et al., 2017) or the belief that others possess more accurate information (informational conformity) (Asch, 1951; 1956). An increased curiosity towards items that received a great number of social network upvotes (Dubey et. al., 2021); assigned higher attractiveness ratings to faces that were found attractive by peers (Zaki et. al., 2011); or shifting clothing preferences towards similar others, and away from dissimilar others (Izuma & Adolphs, 2013) are all examples of social normative conformity. While the value attributed to the observed individual plays a crucial role in conformity, social contagion can occur merely through observation.

The current thesis aims to examine the social contagion of challenge-seeking behaviour in experimental settings. Considering the scarcity of prior research that directly addressed the topic, the primary research question seeks to explore whether observing someone seeking or avoiding challenges would influence the observer's challenge-seeking tendencies.

Intending to answer the research question, a challenge-seeking task was adapted from a forced choice paradigm used in Suzuki's (2016) risk contagion experiments. In this paradigm, participants' risk preferences were operationalized based on their choices to gamble rather than taking a guaranteed $10. Participants' references for risk were compared before and after observing the risk preferences of others behaving in a risk seeking and risk averse manner. The difference between the participants' risk preferences before and after watching the risk preferences of another person was defined as risk contagion.

In the version adapted to the aims of the current study, participants' challenge-seeking preferences, quantified as the frequency of choosing difficult word problems over easier ones, were compared before and after observing others behaving in a challenge-seeking and challenge-avoiding manner. A change between the challenge-seeking tendencies of the participants before and after they observed others selecting word problems in a challenge-seeking and challenge-avoiding manner was defined as the social contagion of challenge-seeking. Experiments reported here used a modified version of this paradigm, as each investigated a different aspect of the social contagion of challenge-seeking behaviour. The set of experiments conducted is delivered in three distinct chapters.

The first chapter comprises five online experiments which were conducted to measure the changes in participants' challenge-seeking behaviours in response to the video recordings (Experiment 1) and replayed choices (Experiment 2) of others, the relationship between social contagion of challenge-seeking and achievement goals and trait intrinsic motivation (Experiment 3), and the contribution of possible changes in perceived task difficulty and self-confidence on the social contagion effect (Experiment 4). The chapter also includes a preregistered online experiment (Experiment 5). The second chapter reports a behavioural experiment that generalised the social contagion of challenge-seeking observed in online experiments to physical encounter settings (Agent Likeability Experiment). This experiment was conducted to measure the effect of agent likeability on the social contagion of challenge-seeking behaviour. The third chapter covers the fMRI experiment conducted to investigate the neural representation of the social contagion of challenge-seeking.

It was hypothesized that watching someone frequently selecting difficult word problems over easier ones would facilitate the participants' challenge-seeking tendencies while watching another person frequently selecting easier word problems over difficult ones would diminish it. The experiments reported in the second chapter mainly focus on this hypothesis. It was also hypothesized that the behavioural shift in participants' challenge-seeking tendencies would be pronounced if the participants were to find the person watched likeable (the rationale for this hypothesis is described in Chapter 3). The results testing this hypothesis are described in Chapter 3. Finally, based on the previous findings of increased striatal activation in response to challenge-seeking and intrinsically motivated behaviours (Murayama et al., 2010; Schouppe et al., 2014; Lee & Reeve, 2017; Sakaki et al., 2022), and increased activations in the ACC in response to decision conflict (Ernst et al., 2004) and recruitment of cognitive resources for a highly demanding task (Kong et al., 2005; Vassena et al., 2014), it was hypothesized that the social contagion of challenge-seeking was represented in the striatum and ACC. This hypothesis is discussed in Chapter 4.

Chapter 2: Behavioural Social Contagion of Challenge-Seeking

2.1. Introduction

The social contagion of challenge-seeking has not been directly measured before, but individuals' beliefs about their competence, which determine their challenge-seeking behaviours, were suggested to be socially structured. Bandura (1977) argued that individuals' self-efficacy (perceived competence) is formed by witnessing the capabilities of similar others and/or verbal persuasion from trusted others. For instance, one's belief about being able to pass a difficult exam strengthens after seeing a classmate with a similar academic standing ace the same exam or hearing words of encouragement from a teacher. Previous research supporting this theory revealed that children's self-competency beliefs were shaped by their teachers' evaluations (Spinath & Spinath, 2005).

The main research question that the current experiments set out to answer is whether challenge-seeking behaviours would be transmitted via social interactions. More specifically, whether observing the challenge-seeking behaviours of others would impact individuals' own challenge-seeking tendencies. It is hypothesised that, observing the challenge-seeking behaviours of another person would increase the likelihood of the observer seeking challenges in the future, while observing the challenge-avoiding behaviours of another would diminish it.

This chapter delivers the methods and results of five behavioural experiments conducted to address the social contagion of challenge-seeking behaviour. Each of these experiments was designed to test a possible change in challenge-seeking tendencies of the participants before and after observing the challenge-seeking behaviours of two confederates with different behavioural patterns. Using a novel challenge-seeking task in which challenge-seeking behaviour was operationalised as participants' tendencies to choose difficult word problems over easier ones, possible influences of observing another's challenge-seeking behaviours were assessed.

2.2. Experiment 1

This experiment was aimed to investigate whether watching the screen recordings of strangers behaving in a challenge-seeking or challenge-avoiding manner would evoke similar challenge-seeking/avoiding tendencies in the observer. The study compared participants' challenge-seeking behaviours before and after observing two confederates with opposite behaviours using a within-subjects design.

Hypothesis: Participants’ challenge-seeking tendencies would be influenced by their perceptions of confederates’ challenge-seeking behaviours. Based on the hypothesis, the following predictions are made:

1. Participants’ baseline preference for difficult word problems would increase after observing the confederate who frequently chooses difficult word problems.
2. Participants’ baseline preference for difficult word problems would decrease after observing the confederate who frequently chooses easy word problems.

2.2.1 Method

2.2.1.1. Participants

68 (24 females, 1 other) participants were recruited using Prolific. The sample size was based on the study budget. Ages ranged from 18 to 46 and the mean age was 22.30 (*SD* = 5.00). Their mean math anxiety score was 2.40 (*SD* = 1.26) out of 6. Sensitivity analysis (performed using G*Power 3.1.9.7, with a significance level (α) of .05, a power of .80) indicated a minimal statistically detectable effect size of 0.34 (*dz*).

Participants were screened for statistical analysis using a participant exclusion criterion determined after Experiment 1. Participants were excluded if they answered “no” to the manipulation check question asking whether they believed the confederates were real people. 28 participants (8 females) were excluded using this first criterion. Furthermore, participants who performed poorly in the prediction trials were excluded from the statistical analysis. These participants predicted that (1) the challenge-avoider confederate would select harder word problems more often; (2) the challenge-seeker confederate would select easier word problems more often, and (3) both would select equal number of harder word problems. 5 participants (1 female) were excluded from the statistical analysis using the second criterion.

The final sample consisted of 35 (15 females, 1 other) participants. Resulting populations’ ages ranged from 18 to 34 (*M* = 22.10, *SD* = 3.90). Their mean math anxiety score was 2.40 (*SD* = 1.40) out of 6. Excluded participants’ age (*M* = 22.52, *SD* = 6.02), gender (9 females), and math anxiety (*M* = 2.39, *SD* = 1.14) were not significantly different from the included participants’ age: $t(54.20) = 0.32$, $p = .747$, $d =$

0.08; math anxiety: $t(65.00) = 0.02$, $p = .984$, $d = .005$; or gender: $x^2(1, N = 67) = 1.40$, $p = .237$, $w = 0.21$.

Anonymised data, analysis codes, and supplementary analyses & materials of Experiment 1-5 are available in Open Science Framework (osf.io/qkrea).

2.2.1.2. Experimental Procedure

Participants first read the information sheet; then filled out the consent form and the demographic information survey. During the instructions phase, participants were presented example word problems to give them an idea about what to expect (Appendix A). When they finished reading the instructions, they practiced the challenge-seeking task for the duration of 3 trials and they were requested permission to record their word problem choices anonymously for future participants of the study to view. Those who accepted chose an avatar image across various cartoon animal images and created a nickname for themselves. Unbeknownst to the participants, their choices were not shared with the future participants of the study. This procedure was used to maintain the plausibility that the two confederates demonstrated throughout the experiment were recordings from the previous participants of the study. After choosing a nickname and an avatar image, they saw the avatar image and the nickname chosen by each confederate. The avatar image selected for the confederate was always different from the participants' choice. The nicknames for the confederates were selected among the fake words created using a random name generator (Random Word Generator, n.d.) and did not have any meaning in English (e.g., Writuall).

When the instructions were over, participants proceeded to the challenge-seeking task. The task was programmed in JavaScript using a combination of built in plugins in jsPsych version 6.3 (de Leeuw, 2015) and their modified versions. When participants completed the challenge-seeking task, they worked on the post-experiment tasks and surveys. Before being redirected to Prolific, participants were thanked, presented with a debrief form and compensated with £10 per hour of their time. This study was approved by the University Research Ethics Committee at University of Reading (UREC; Ethics Approval number: UREC 21/08).

Challenge-Seeking Task: In each trial, a pair of red-grey pie charts representing the difficulty level of different word problems were presented on a white background (Figure 1). Participants were informed that the percentage values on each pie chart indicated the proportion of participants in a large sample pilot study who gave a correct answer to the word problem that the pie chart represented. For instance, a pie chart showing 40% correct answer rate meant that 40% of the participants in the pilot study answered that word problem correctly. Note that the actual word problems were not presented to the participants to avoid the potential effects of the contents of the word problems, but participants were led to believe that each pie chart represented a different word problem, which they might have worked on after the task (see the explanation about "make-your-choice trials" below). In this task, choosing the word problem with lower correct answer rate was considered a challenge-seeking behaviour (i.e., preference for a more challenging/difficult task).

The correct answer rate of each pie chart was selected from one of the three difficulty settings: easy setting (ranged from 78% to 98%), medium setting (ranged from 40% to 60%) and difficult setting (ranged from 2% to 22%). In each trial, participants were presented with pie charts showing a two-way combination of these difficulty settings. For instance, suppose that the correct answer rate of the left pie chart was 15% and the correct answer rate of the right pie chart was 50%. In this scenario, participant compared a difficult word problem (15%) to a medium difficulty word problem (50%). Please note that the participants were unaware that the correct answer rate values belonged to different difficulty categories.

Participants were instructed to respond by moving the cursor towards the pie chart of their choice. The pie chart was highlighted in yellow when hovered; highlighted in orange when clicked. After choosing a pie chart, participants were instructed to click on the 'submit my decision' button to move on to the next trial.

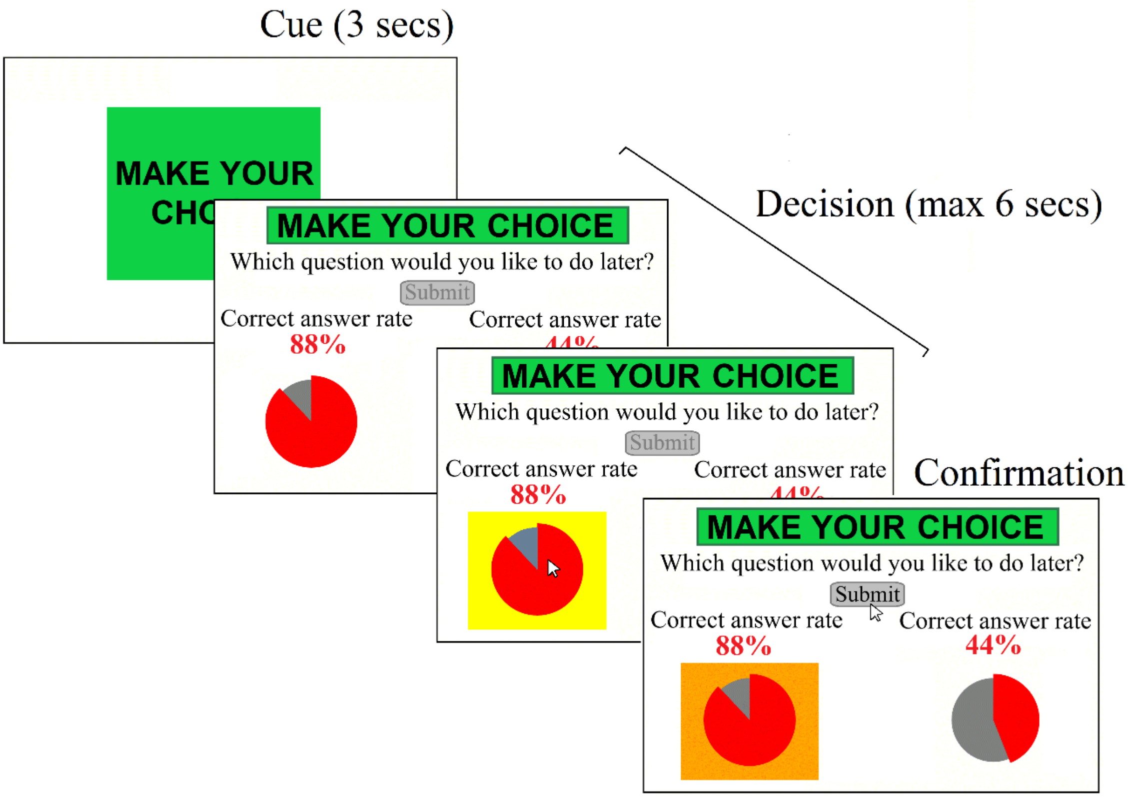
In between sessions, participants were reminded of what was expected of them. At the end of each session, they were presented with the following statement: "Please wait. Your preferences are recorded to your question pool". This instruction was used to emphasise the problem-solving session at the end of the experiment and to remind the participants to make their word problem choices accordingly.

There were three types of trials. The first type was *make-your-choice* trials in which participants' baseline challenge-seeking tendencies were measured. The second type was *observe* trials in which participants observed the challenge-seeking behaviours of confederates. The third type was *predict* trials in which participants' learning of confederates' challenge-seeking tendencies were tested. The details of each type of the trials are described below.

Make-Your-Choice Trials. In the make-your-choice trials, participants were asked to choose a word problems that they would like to solve based on the correct answer rates (difficulty) written (and demonstrated) on the pie charts. Participants were instructed that their word problem choices during make-your-choice trials would constitute their personal question pool. They were led to believe that, at the end of the experiment, they would be asked to solve five word problems randomly selected from their question pool. There were 18 make-your-choice trials per session. A green coloured 'make your choice' cue was presented at the top centre of the screen. Below the green cue image, participants saw the following statement: "Which word problem would **YOU** like in your question pool?" (Figure 1). A green cue image that said "make your choice" was presented for 3 seconds to signal the beginning of these trials. Once the make-your-choice trials started, participants had 6 seconds to respond, after when they were presented a warning sign in red that said "miss".

Figure 1.

Timeline of make your choice trials in challenge-seeking task, as appeared in Experiment 1



Note. Make your choice trials started with a green cue image that stayed on the screen for 3 seconds (1st frame). When the two pie-charts appeared on either side of the screen, participants had 6 seconds to respond (Decision phase). During this time, if hovered, the rectangular region around the pie chart was highlighted in yellow (3rd frame in the figure). If clicked, the rectangular region turned to orange colour (4th frame in the figure). Participants clicked on the submission button to move on to the next trial (in the 4th frame). The submission button was activated only after participants selected a pie chart.

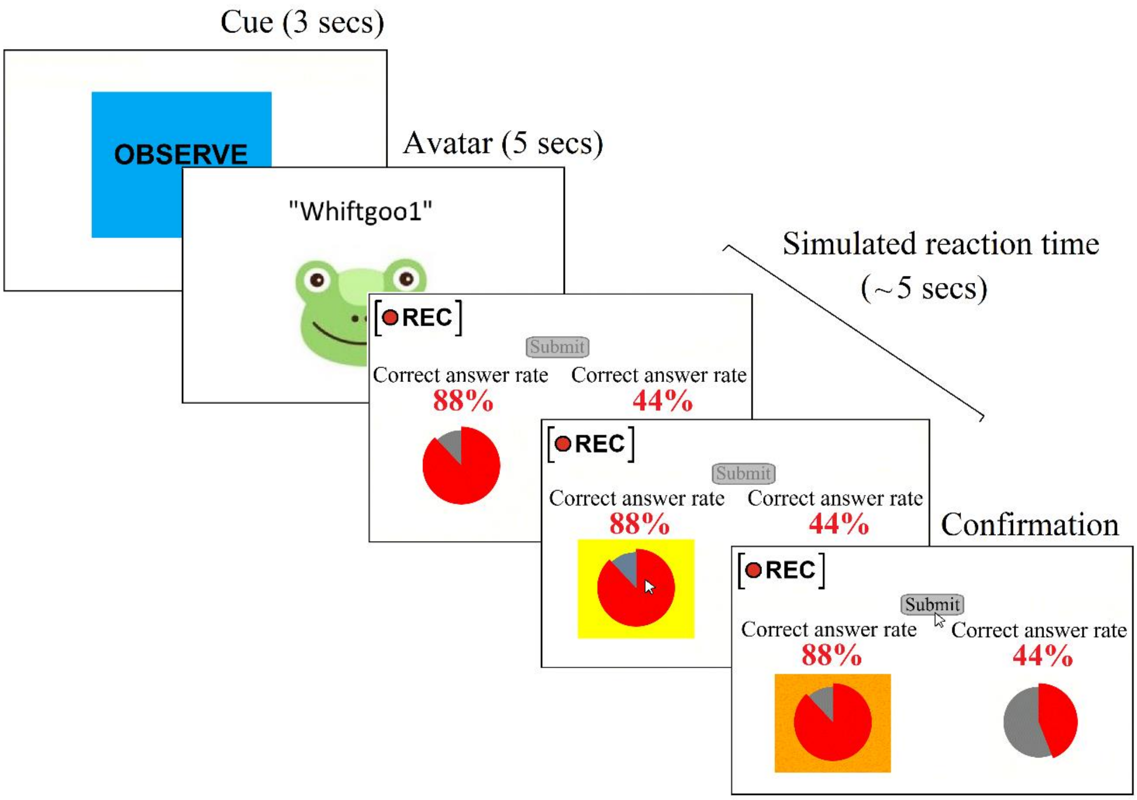
Observe Trials. In observe trials, participants passively watched short videos of pie charts being selected by two different confederates. Unbeknownst to the participants, these choices were generated by the experimenter to simulate the behaviours of two confederates. Each video consisted of 9 trials in which the experimenter moved the mouse cursor to select the pie chart on the left or the right side of the screen (based on the confederate's predefined challenge-seeking tendency) and moved back to the middle of the screen to click the submission button. (Figure 2). Each trial lasted approximately 5 seconds (simulated reaction time ~= 5 secs).

In each video, either 8 difficult word problems and 1 easy word problem, or 8 easy word problems and 1 difficult word problem, were selected. Videos dominant with difficult word problem choices (8 difficult and 1 easy word problems) were created to mimic a challenge-seeker individual, who is referred to as the *challenge-seeker confederate* from now on. Videos dominant with easy word problem choices (1 difficult and 8 easy word problems) were created to mimic a challenge-avoider individual, who is referred to as the *challenge-avoider confederate* from now on. Out of 9 choices, 1 intentionally displayed a behaviour opposite to the confederate's orientation in order to simulate human-like random behaviours (e.g., challenge-seeking confederate choosing an easier word problem). This trial is referred to as *confederate incongruent trial*. 18 videos were created to randomise the presentation of confederate incongruent trial. In each video, the presentation of the confederate incongruent trial had a different order number in the list of 9 word problems (e.g., in the 1st video, confederate irregular trial was presented in the 5th trial, but in the 2nd video, it was presented at the 3rd trial). Presentation of videos was randomised for each participant. Note that the videos were cropped not to show the question present in make your choice trials (Which word problem would **YOU** like in your question pool?). This part was cropped to avoid confusing the participants about what was expected of them (to prevent the participant from responding rather than observing).

A blue-coloured image that said 'observe' was presented for 3 seconds to signal the beginning of observe trials. The avatar image and the nickname of the confederate were presented for 5 seconds right after the cue image.

Figure 2

Timeline of observe trials in challenge-seeking task, as appeared in Experiment 1



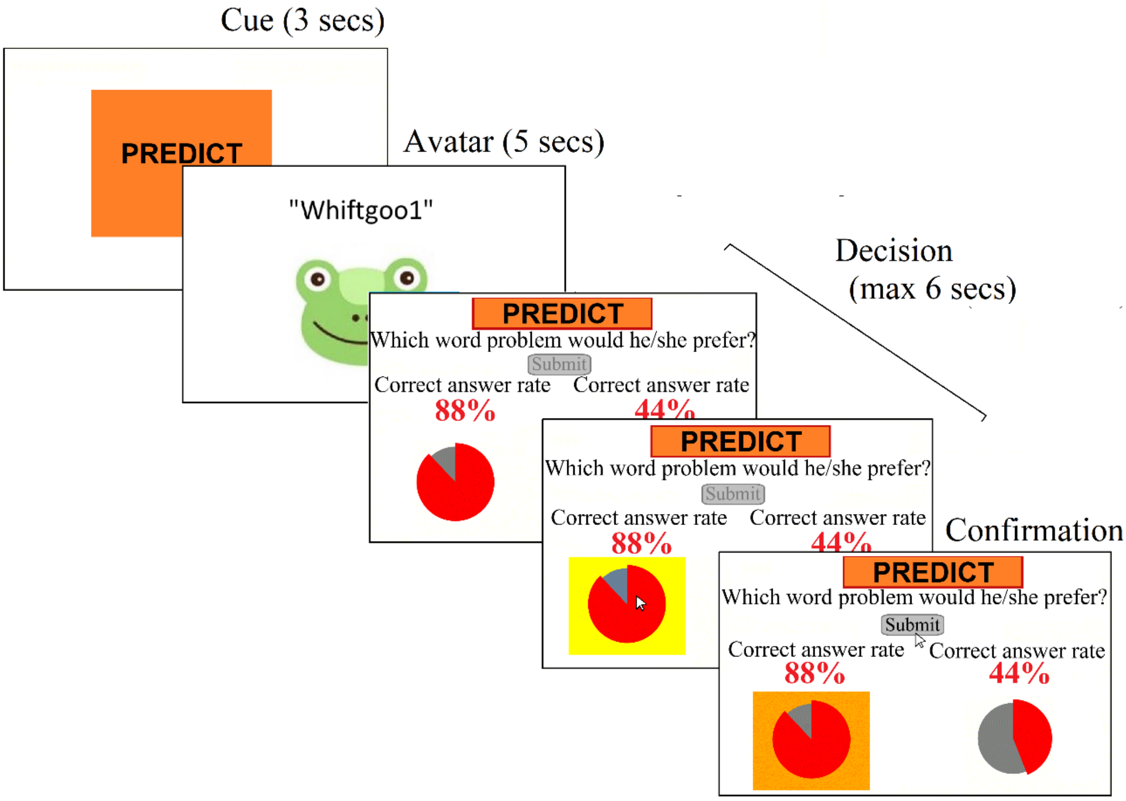
Note. Observe trials started with a blue cue image that stayed on the screen for 3 seconds (1st frame) and followed by the confederate's avatar image that stayed on the screen for 5 seconds (2nd frame). A video consisting of 9 consecutive trials was played for approximately 45 seconds. Each trial started with the presentation of a different pair of pie charts presented for 5 seconds (simulated reaction time) after which the mouse cursor moved towards one of the pie charts and clicked on it (3rd and 4th frames). The trial ended when the mouse cursor moved to the submission button and clicked it (5th frame).

Predict Trials. Observe trials were followed by the predict trials. In these trials, participants were presented with a pair of pie charts, and asked to guess which word problem the confederate, who they had just observed, would select. These trials were useful in eliminating the participants who did not pay attention to the choices of the confederates during the observe trials or those who could not learn the challenge-seeking tendencies of two differently behaving confederates. There were 18 predict trials per session. At the top centre of the screen, participants could see the question: "Which word problem would he/she prefer?".

An orange cue image that said ‘predict’ was presented at the centre of the screen for 3 seconds to signal the start of the predict trials. The avatar image and the nickname of the confederate followed the cue image and stayed on the screen for 5 seconds (Figure 3). As in make-your-choice trials, participants were asked to respond within 6 seconds, after when they were presented a warning sign in red that said “miss”.

Figure 3

Timeline of predict trials in challenge-seeking task, as appeared in Experiment



Note. Predict trials started with an orange cue image that stayed on the screen for 3 seconds (1st frame) and followed by the confederate’s avatar image that stayed on the screen for 5 seconds (2nd frame). When the two pie-charts appeared in either side of the screen, participants had 6 seconds to respond (Decision phase). During this time, if hovered, the rectangular region around the pie chart was highlighted in yellow (3rd and 4th frames). If clicked, the rectangular region turned to orange colour (5th frame). Participants clicked on the submission button to move on to the next trial (5th frame). The submission button was activated only after participants selected a pie chart.

Three types of trials were systematically placed in five separate sessions of the experiment (Figure 4). The first session consisted of 18 “make-your-choice” trials which was used to assess participants’ challenge-seeking behaviour before the experimental manipulation (baseline challenge-seeking). In sessions 2 and 4, observe and predict trials were intermixed with four blocks of 9 trials, with the aim to teach and test the behavioural patterns of the confederates, respectively. Challenge-seeker and challenge-avoider confederates were assigned to different sessions and the order of the confederates was counterbalanced across participants. Sessions 3 and 5 also consisted of 18 make-your-choice trials each. Here, the aim was to assess the effects of observing the challenge-seeker and challenge-avoider confederates on participants’ word problem choices. Experiment 1 had a total of 126 trials and lasted for 20-25 mins.

Figure 4

Session structure of Experiment 1

Note. Word problem choices of challenge-seeker and challenge-avoider confederates were presented during observe trials, in sessions 2 and 4. The order of observing the challenge-seeker or challenge-avoider confederate was counterbalanced across participants. According to the session structure presented in the figure, challenge-seeker confederate was observed first (in Session 3). The participant’s baseline challenge-seeking behaviours were measured in Session 1. The influence of observing a challenge-seeker confederate was assessed in Session 3, and the influence of observing a challenge-avoider confederate was assessed in Session 5.

2.2.1.3. Surveys and Additional Tasks

At the end of the challenge-seeking task, participants were asked to solve five word problems. Unbeknownst to the participants, these word problems were not selected from their word problem pool that they created during make-your-choice trials. Each participant was presented with the same set of 5 word problems. After each word problem, they were requested to rate their confidence in their answer, curiosity evoked by the word problem and its perceived difficulty. Participants' performance in these word problems was not subjected to statistical analysis.

Furthermore, participants' math anxiety and math self-concept were measured for exploratory purposes. Math anxiety was measured using the following single item: "On a scale from 1 to 5, how math anxious are you" (Núñez-Peña et al., 2014). Math self-concept was measured using 6 items (e.g., "It is easy to understand things in math") in which participants provided ratings on a 5-point scale from not true (1) to absolutely true (5) (Marsh et al., 2019). Item reliability was good (Cronbach's α was .94). Additionally, a manipulation check survey was administered to measure participants' attention for the task and as an experimental manipulation check. The survey included a binary question (yes/no) asking about the plausibility of confederates in the online experiment ("Did you believe that the participants you watched were real people? If not, why?"). This item was used to exclude participants (see Participants Section in Experiment 1 for more details).

2.2.2. Data Analysis

Participants' word problem choices were measured at three time points: baseline, after observing the challenge-seeker confederate and after observing the challenge-avoider confederate. For the ease of legibility, these time points will be referred as (1) baseline, (2) challenge-seeker, and (3) challenge-avoider conditions.

The main dependent variable was challenge-seeking rate, which was operationalised as the proportion of make-your-choice trials in which the participants chose to solve the more difficult word problem. Each participant had three challenge-seeking rates, corresponding to their difficult word problem choices in sessions 1, 3, and

5. The shift in challenge-seeking behaviours across observation conditions was quantified as the absolute difference between the challenge-seeking rates in 2 observation conditions (e.g., |challenge-seeking rate in challenge-seeker condition - challenge-seeking rate in challenge-avoider condition|).

Data analysis was conducted using RStudio 2022.7.1.554 (RStudio Team, 2022) and IDE for R version 4.1.3 (R Core Team, 2022). Mixed ANOVA was conducted using the 'anova_test' function from the 'rstatix' library (Kassambara, 2022). Post-hoc t-tests were conducted using the 'pairwise_t_test' function in the 'stats' library (R Core Team, 2022) and corrected for multiple comparisons using the Bonferroni-Holm method. Exploratory logistic GLM analysis was conducted using the 'glmer' function from the 'lme4' library (Bates et al., 2015). Meta-analysis was conducted using the 'metafor' library (Viechtbauer, 2010). Figures were created using the 'ggplot2' (R Core Team, 2022) and 'metafor' libraries as well as the 'Open-visualizations in R and Python tutorial' (Langen, 2020).

Please note that the variables of interest and the data analysis tools were the same for Experiments 1-5. Therefore, data analysis details are not repeated under each experiment's method section.

2.2.3. Results

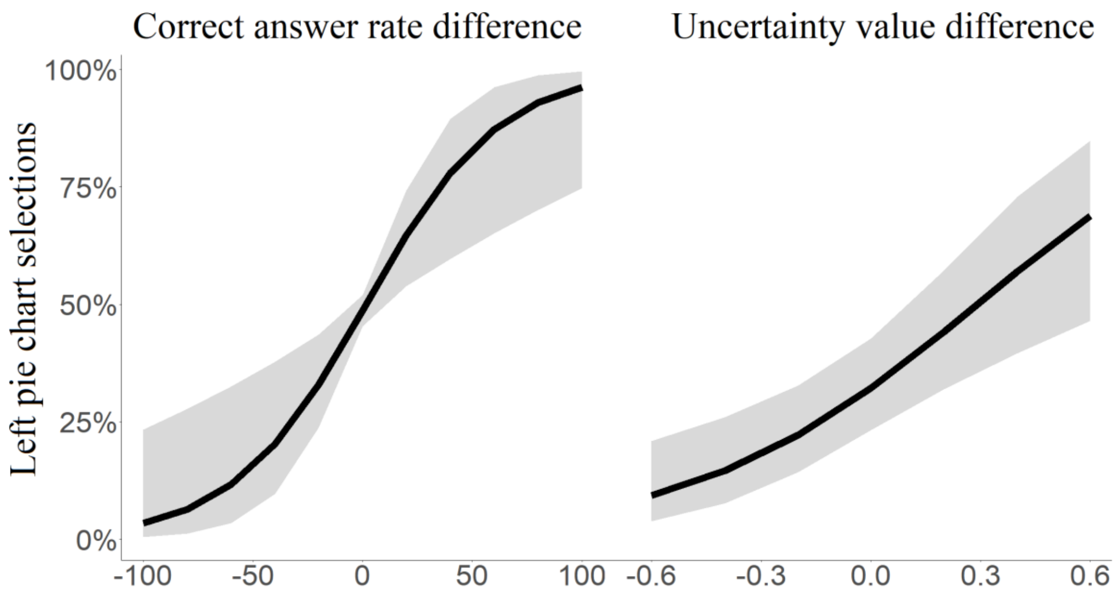
2.2.3.1. Participants' Challenge-Seeking at Baseline

At baseline, participants often avoided challenging word problems. Their challenge-seeking rate was .30 (SD = .31). This challenge avoidant tendency was especially prevalent when the difference between the accuracy levels of the two options was greater. A mixed-effects logistic regression model predicting word problem selection by the correct answer rate difference between the two word problems (i.e., larger difference indicated that chosen word problem was presented as more challenging than the unchosen one) showed a decrease in the choice of harder word problem with the increase between the options' correct answer rates, β = 0.03, SE = 0.009, 95% CI [0.01, 0.05], p = .003. This finding indicated that participants' choices were not random; they were highly guided by the difficulty level of the word problems.

Based on the literature suggesting that uncertainty is a driving factor of information-seeking behaviour (van Lieshout et al., 2021), the role of uncertainty resolution in choice behaviour was also explored. Specifically, an entropy value was calculated for each pie chart using Boltzmann's entropy equation (Chamberlain & Hunten, 1990), and the difference in entropy values of the pie charts was defined as the entropy value of the trial. Note that entropy is the largest if the accuracy is 50%. The entropy value of the trial was added to the previous mixed-effects logistic regression. Results revealed that the participants were more likely to select the higher entropy option as the difference between the pie charts' entropy values increased, $\beta = 2.56$, $SE = 0.70$, 95% *CI* [1.19, 3.94], $p < .001$. The effects of accuracy difference also stayed significant, $\beta = 0.03$, $SE = 0.01$, 95% *CI* [0.01, 0.05], $p = .003$ (Figure 5). These results demonstrated that participants' choice was also guided by the uncertainty of their success. The word problems with accuracy values around 50% were preferred more frequently.

Figure 5.

Left pie chart selection by the difference between left and right pie charts' correct answer rate and uncertainty value



Note. Participants were more likely to select the left pie chart as the difference between the left and right pie chart's (left panel) correct answer rates and (right panel) the uncertainty values increased.

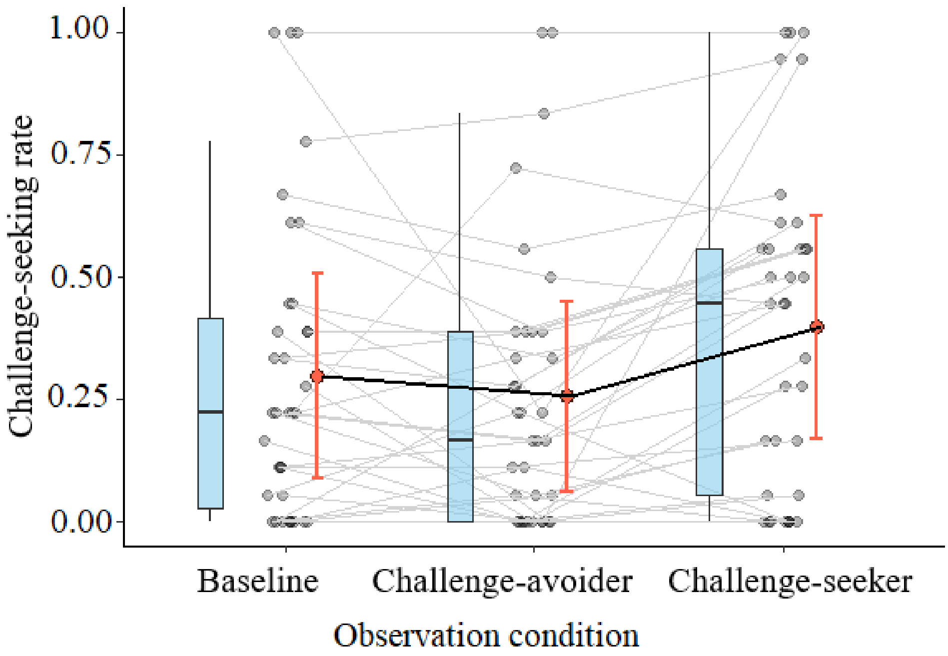
2.2.3.2. Social Effects of Confederates' Choices on Participants' Challenge-Seeking

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA indicated a significant main effect of observation condition, $F(2, 66) = 6.96$, $p = .002$, $\eta_G^2 = .04$. Neither the confederate order nor the interaction between confederate order and observation condition had any effect on challenge-seeking rates, $F(1, 33) = 0.03$, $p = .869$, $\eta_G^2 = .001$., $F(2, 66) = 0.20$, $p = .816$, $\eta_G^2 = .001$.

Individual paired samples *t*-tests showed significantly greater challenge-seeking rates in the challenge-seeker condition compared to the challenge-avoider condition, $t(34) = 3.67$, $p < .001$, $dz = 0.62$ (Holm adjusted alpha level = 0.02,). Challenge-seeking rates were not significantly different across baseline and challenge-seeker conditions, $t(34) = 2.37$, $p = .047$, $dz = 0.4$ (Holm corrected alpha level = 0.03) or between baseline and challenge-avoider conditions, $t(34) = 1.21$, $p = .235$, $dz = 0.2$ (Holm corrected alpha level = .05) (Figure 6).

Figure 6

Challenge-seeking rates across observation conditions for Experiment 1



Note. Each participant's challenge-seeking rate for each observation condition are presented with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition are demonstrated with red dots and connected with dark black lines.

2.2.3.3. Exploratory Analyses

Building on the result indicating participants' preference for high entropy word problems, their uncertainty resolution behaviours were compared across observation conditions. Choosing the word problem with correct answer rate value closer to 50% was defined as an uncertainty resolution behaviour. A mean uncertainty resolution rate was calculated for each observation condition. A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA did not indicate a significant effect of observation condition, $F(2, 66) = 0.82$, $p = .447$, $\eta_G^2 = .01$, confederate order, $F(1, 33) = 0.21$, $p = .652$, $\eta_G^2 = .01$, or their interaction, $F(2, 66) = 0.13$, $p = .877$, $\eta_G^2 = .001$ on the uncertainty resolution rates. Therefore, it is unlikely that the observed behavioural shift across observation conditions is related to uncertainty resolution behaviour.

Additional exploratory analysis revealed that behavioural shift across observation conditions were not correlated to participants' age, gender, math anxiety or math self-concept (Appendix B).

2.2.4 Conclusions

Results partly support the first hypothesis that observing a challenge-seeker confederate increased challenge-seeking behaviour. However, although the challenge-seeking rates in challenge-seeker condition was greater than baseline, the difference was not significant. Contrary to the second hypothesis, observing a challenge-avoider confederate did not decrease the challenge-seeking behaviour relative to the baseline.

Importantly, about one third of the participants were eliminated from the statistical analysis (reported under Methods section) for stating their doubts about plausibility of the experiment. In the post experiment survey, most of these excluded participants reported that the use of videos in observe trials raised suspicion about the confederates. Some of them suggested that it would be unlikely to record participants' screen during an experiment (remember that these participants were told that observe trials were word problem choices of previous participants of a similar study). Some other stated that 5 seconds were too long for a real person to respond (remember that the simulated reaction time was 5 seconds). According to excluded participants' feedback, it is possible that participants' doubts about the confederates might have hindered the expected social contagion of challenge-seeking/-avoiding behaviours.

The risk contagion experiment from which the challenge-seeking task was adapted (Suzuki et al., 2016) used a similar setup in which participants watched confederates gambling in the observe condition. Importantly, the recordings they showed to their participants (in the observe trials) had a wider angle and it contained the back of the confederates' head in addition to their computer screen. Therefore, one might argue that involving the confederate in the shot would be a better way of facilitating the plausibility of the confederate. Although it worked for studying risk contagion, it would have introduced a confounding variable for the challenge-seeking task. Participants' challenge-seeking behaviours would have been influenced by how they wished to be seen by other people. Remember that participants were asked for permission to record their word problem choices at the beginning of the experiment. Even if they were to reject to give permission, just the idea of being recorded would have activated thoughts about being evaluated or simply being viewed by others. These thoughts would have led to the adoption of performance achievement goals (Ames, 1992; Jagacinski et al., 2008), which might not necessarily represent their actual challenge-seeking tendencies (e.g., choosing word problems based on the impression they want to build for the future participants to see). In consideration of the interference of performance achievement goals, participants were ensured that theirs (and confederates') identities would be protected by anonymising the recordings with the use of nicknames and avatar images. If the current design were to use videos showing the back of their head, participants would not be convinced easily that the videos recorded could be anonymised. Therefore, videos created for Experiment 1 did not show the confederate's head.

Incorporating the feedback from participants' reports regarding confederate plausibility and efforts not to activate performance achievement goals, an improved version of the experiment was created (Experiment 2). In this version, participants observed the replayed choices of confederates, rather than raw video recordings.

2.3. Experiment 2

The aim of Experiment 2 was to investigate the effects of observing the challenge-seeker and challenge-avoider confederates on participants' own challenge-seeking, after eliminating the factors that might have led the participants of Experiment 1 to doubt the plausibility of the confederates. The improved version employed extra features to facilitate confederate plausibility, such as using simulations of keyboard responses in observe trials rather than simulations of mouse responses which cannot fully mimic human-like mouse movements (explained in more detail under Experimental Procedure section).

Hypothesis: Participants' challenge-seeking tendencies would be influenced by their perceptions of confederates' challenge-seeking behaviours. Based on the hypothesis, the following predictions were made:

1. Participants' baseline preference for difficult word problems would increase after observing the challenge-seeker confederate.
2. Participants' baseline preference for difficult word problems would decrease after observing the challenge-avoider confederate.
3. Participants' preference for difficult word problems after observing the challenge-seeker confederate would be greater than their preference for difficult word problems after observing the challenge-avoider confederate.

2.3.1. Method

2.3.1.1. Participants

80 (37 females) participants were recruited using Prolific. The sample size was pre-determined based on the study budget. Participants' age range was between 18 to 36 and the mean age of the population was 22.95 (*SD* = 3.68). Their mean math anxiety scores were 2.49 (*SD* = 1.31) out of 6. Sensitivity analysis (performed using G*Power 3.1.9.7, with a significance level (α) of .05, a power of .80) indicated a minimal statistically detectable effect size of 0.32 (*dz*).

Participants were screened for statistical analysis using the same criteria set in Experiment 1 (confederate plausibility and prediction accuracy). 20 participants (9 females) were excluded due to confederate plausibility and 8 participants (4 females) were excluded for incorrectly predicting the challenge-seeking tendencies of the confederates. Age range of the remaining population was between 18 to 36 and the mean age was 22.73 (*SD* = 3.47). Mean math anxiety was 2.50 (*SD* = 1.20). Excluded participants' age (*M* = 23.36, *SD* = 4.09), math anxiety (M = 2.39, SD = 1.47) and gender were not significantly different from the included participants' age, *t*(48.13) = 0.69, *p* = .495, *d* = 0.17, math anxiety, *t*(47.44) = 0.45, *p* = .658, *d* = 0.11 or gender, $x^2(1, N = 80) = 0.00$, *p* = 1.00.

2.3.1.2. Experimental Procedure

Procedure used in Experiment 2 was similar to the one in Experiment 1 except for the modifications in Challenge-seeking Task (Figure 7).

Challenge-Seeking Task: The following modifications were made to the challenge-seeking task:

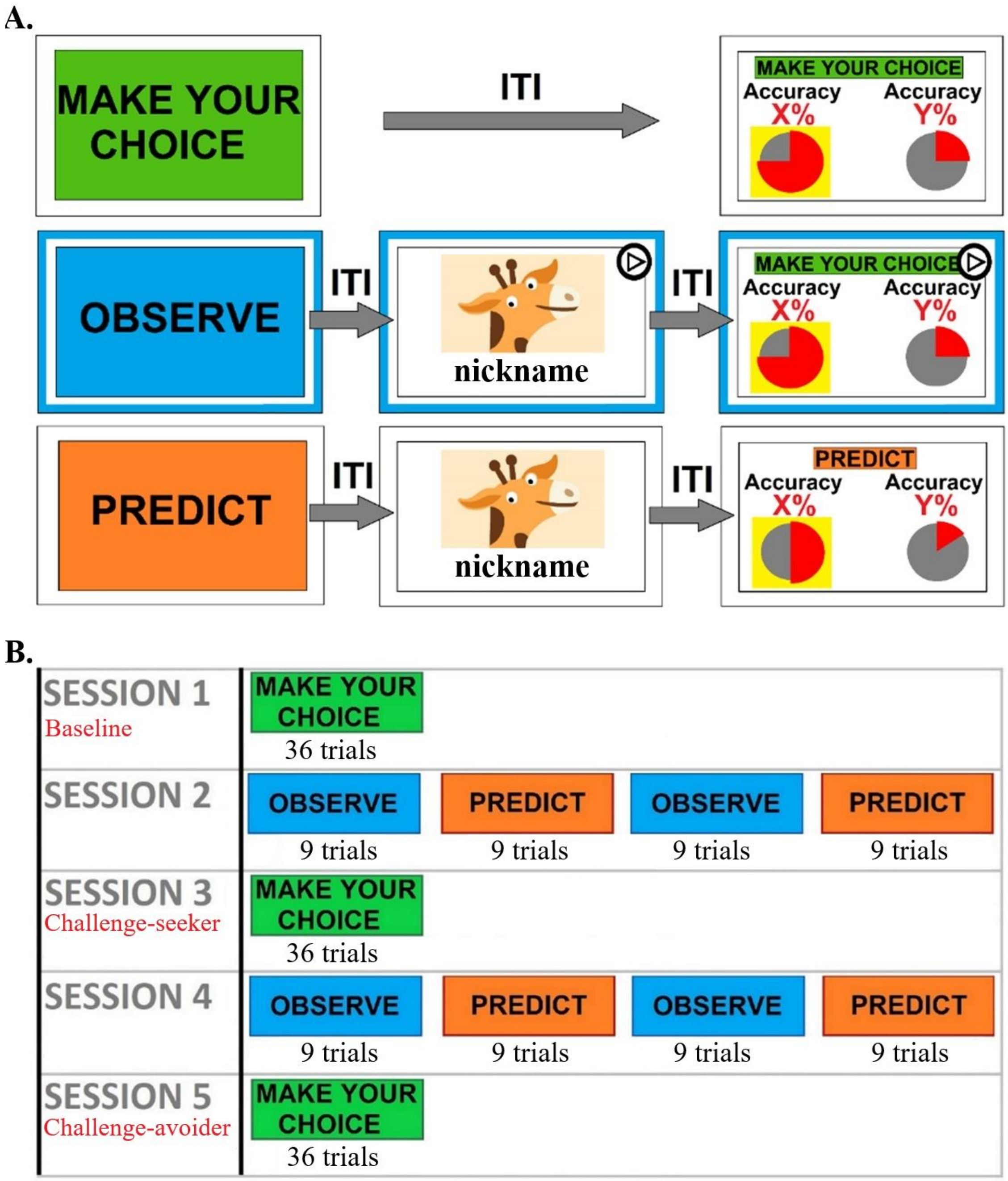
- The number of make-your-choice trials was doubled to 36 trials (in sessions 1, 3 and 5) to increase statistical power. Therefore, the total number of trials was increased from 126 to 180.
- The number of confederate incongruent trials in observe trials was doubled to be 8 out of 36 trials in order to simulate human-like exploration behaviours.
- One out of 14 confederate congruent trials was simulated to mimic a no-response trial. After the 6 second into the trial, a miss trial warning in red (as it appears in make-your-choice and predict trials) was presented. The miss trial was never selected from the confederate incongruent trials.
- Confederates' reaction times were reduced to 1.90 seconds (*SD* = 0.68) based on the participants' mean reaction times to make-your-choice trials in Experiment 1.
- A blue frame was added to the screen during observe trials to remind participants they should only watch, not respond.
- Participants responded using their keyboard, rather than their mouse cursor. Participants were instructed to press on the left arrow key (or A key) to select the left pie chart and the right arrow key (or the D key) to select the right pie chart. The selected pie chart was highlighted in yellow for 1 second.
- The amount of text on the screen was decreased by replacing the term 'correct answer rate' with 'accuracy' and by omitting the questions at the top centre of the screen (Which word problem would **YOU** like in your question pool? / Which word problem would she/he prefer?). The text on screen was minimised to reduce the

cognitive load of reading long task instructions, and have participants concentrate on the decision-making process.

- The submission button was removed. Instead, randomly calculated inter-trial-intervals (ITIs) were added in between trials to prevent habituation. Their duration ranged from 2 seconds to 6 seconds and had a mean of 3 seconds.
- The durations of the condition cues (e.g., green make-your-choice cue) and the avatar images were reduced to 2 seconds.
- Extra instructions in between sessions were removed (e.g., Please wait. Your preferences are recorded to your question pool) as they did not contribute to the confederate plausibility in Experiment 1.

Figure 7

Trial types and numbers as appeared in Experiments 2-5



Note. Coloured boxes show different trial types (make-your-choice, observe and predict). Make-your-choice trials in sessions 1, 3 and 5 were used to measure participants' challenge-seeking, while social manipulations were applied in sessions 2 and 4 using observe trials in which participants watched either the challenge-seeker or a challenge-avoider confederate making word problem choices for themselves and checked using predict trials in which participants guessed the word problem choices of the confederates. (A) Trial structure. Observe trials were highlighted with a light blue frame on the screen. Each trial type was signalled with a cue image for 2 seconds. In observe and predict trials participants saw the nickname and the avatar image of the confederate for 2 seconds after the cue image. ITI stands for inter-trial interval (M = 3 secs, min = 2 secs, max = 6 secs). RT stands for reaction time. (B) Session structure. The number of make-your-choice trials was 36 per session.

2.3.1.3. Surveys and Additional Tasks

At the end of the challenge-seeking task, participants solved five word problems. These word problems were the same as the ones used in Experiment 1 and participants' performance in these word problems and their confidence, curiosity and perceived difficulty ratings for them were not subjected to statistical analysis.

After the word problem-solving session, participants' math anxiety and math self-concept were measured using the same scales used in Experiment 1. The manipulation check survey was similar to that used in Experiment 1, with the addition of the two items asking whether the participants believed that (1) their choices were being recorded during the make-your-choice sessions and (2) five word problems they solved at the end of the experiment were selected from the question pool they created with their word problem selections in the make-your-choice trials.

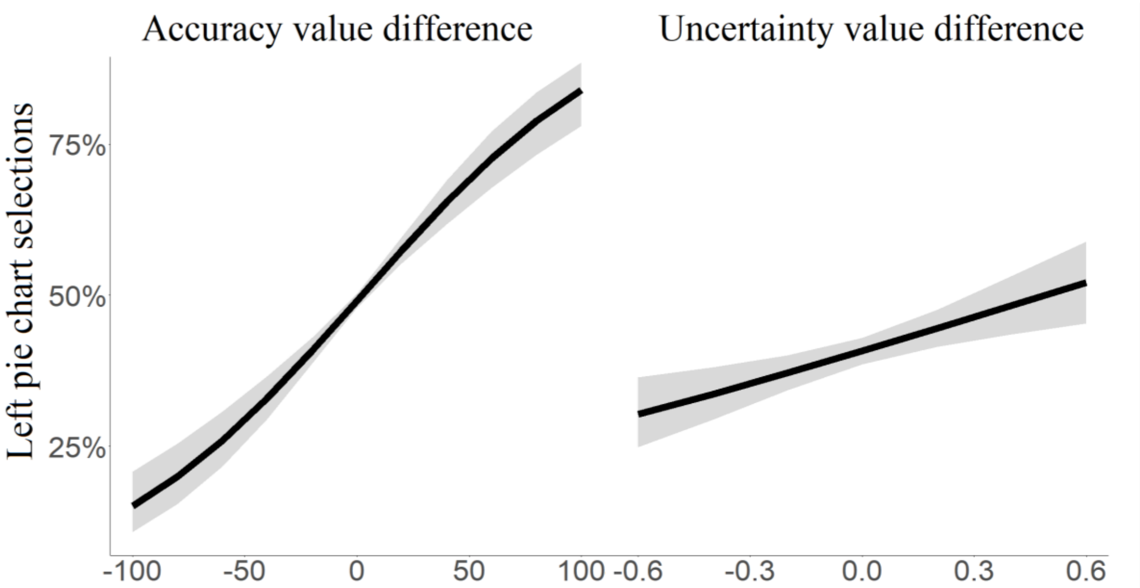
2.3.2. Results

2.3.2.1. Participants' Challenge-Seeking at Baseline

At baseline, the challenge-seeking rate was .18 (*SD* = .25). Participants had a challenge-avoiding approach before any experimental manipulation. A mixed-effects logistic regression model predicting word problem selection by the accuracy (correct answer rate in Experiment 1) difference between the word problems showed that challenge-seeking behaviour reduced as the accuracy difference between word problems increased, $\beta = 0.02$, *SE* = 0.001, 95% *CI* [0.01, 0.02], $p < .001$. Participants' word problem choices were analysed from the uncertainty resolution perspective as well (please refer to Exploratory Analyses section of Experiment 1 for details on uncertainty resolution and entropy measure). Adding the entropy value of the trial to the mixed effects logistic regression revealed a tendency for pie charts with higher entropy value, $\beta = 0.77$, *SE* = 0.22, 95% *CI* [0.33, 1.20], $p < .001$, while leaving the accuracy-difference-based challenge-avoiding tendency significant, $p < .001$ (Figure 8). These findings replicated the results of Experiment 1. Participants' choices were influenced by the word problem accuracy values and uncertainty values.

Figure 8

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

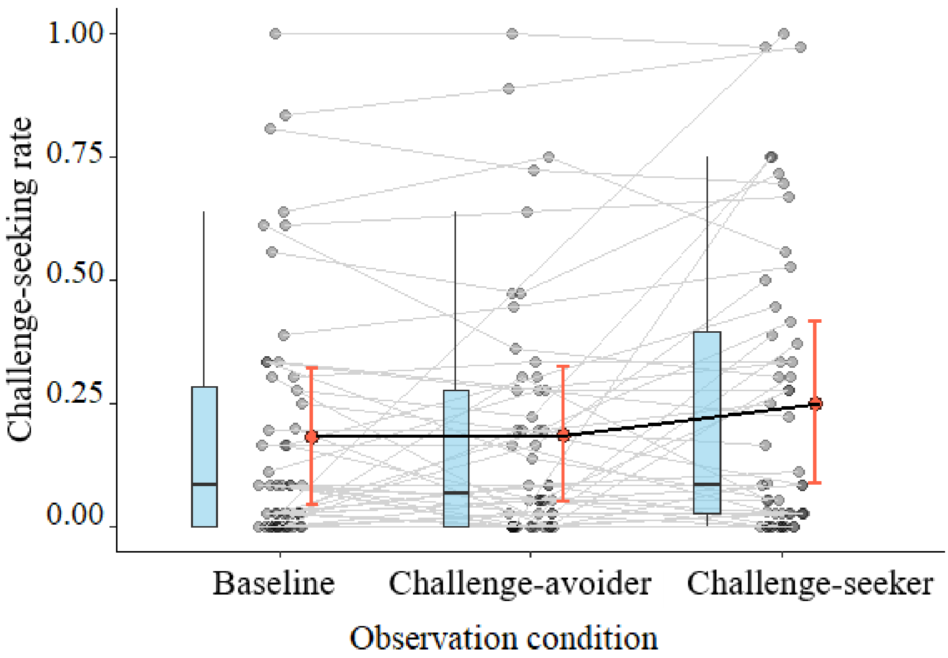
2.3.2.2. Social Effects of Confederates' Choices on Participants' Challenge-Seeking

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA revealed a significant main effect of observation condition, $F(1.45, 72.28) = 4.65$, $p = .022$, $\eta_G^2 = .02$. Regardless of confederate order, challenge-seeking rates were significantly different across baseline ($M = 0.18$, $SD = 0.25$), challenge-avoider ($M = 0.19$, $SD = 0.25$) and challenge-seeker conditions ($M = 0.25$, $SD = 0.30$). Main effect of confederate order did not significantly influence challenge-seeking rates, $F(1, 50) = 1.19$, $p = .281$, $\eta_G^2 = .02$. Participants who observed the challenge-seeker confederate first ($M = 0.24$, $SD = 0.28$) and those who observed the challenge-avoider confederate first did not differ in their general challenge-seeking tendencies ($M = 0.17$, $SD = 0.25$). The interaction effect of confederate order and observation condition also did not significantly influence participants' challenge-seeking rates $F(1.45, 72.28) = 0.37$, p = .621, η_G^2 = .001.

Individual paired samples *t*-tests showed significantly greater challenge-seeking rates in the challenge-seeker condition compared to the challenge-avoider condition, $t(51) = 2.52$, $p = .015$, $dz = 0.35$, (Holm adjusted alpha level = .02). However, challenge-seeking rates were not significantly different across the challenge-seeker and baseline conditions, $t(51) = 2.24$, $p = .029$, $dz = 0.31$, Holm corrected alpha level = .03, and across the challenge-avoider and baseline conditions, $t(51) = 0.30$, $p = .763$, $dz = 0.04$, Holm corrected alpha level = .05 (Figure 9).

Figure 9

Challenge-seeking rates in Experiment 2 for each observation condition



Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition were demonstrated with red dots and connected with dark black lines.

2.3.2.3. Exploratory Analyses

Consistent with Experiment 1, uncertainty resolution behaviour did not change across observation conditions. A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA did not indicate a significant effect of observation condition, $F(2, 100) = 1.65$, $p = .197$, $\eta_G^2 = .01$, confederate order, $F(1, 50) = 0.30$, $p = .588$, $\eta_G^2 = .01$, or their interaction, $F(2, 100) = 0.57$, $p = .565$, $\eta_G^2 = .002$ on the uncertainty resolution behaviours.

The changes in challenge-seeking rates across observation conditions were not correlated with participants' age, gender, math anxiety or math self-concept (Appendix B).

2.3.3. Conclusions

Obtained results replicated the findings of Experiment 1. Observing a challenge-seeker confederate increased participants' challenge-seeking behaviours. Observing a challenge-avoider, on the other hand, did not influence participants' baseline challenge-seeking tendencies. While predictions 1 and 3 were confirmed, prediction 2 was not supported.

In both Experiment 1 and 2, participants showed a general tendency for avoiding difficult word problems and a small effect size in the social contagion of challenge-seeking across certain conditions (i.e., between baseline and challenge-seeker conditions). There might be another factor contributing to the social contagion of challenge-seeking behaviour. A possible candidate might be achievement goals adopted by the participants. Previous literature investigating achievement goals indicated that individuals with mastery achievement goals are more likely to seek challenges and less likely to change their competence judgments and challenge-seeking behaviours based on social factors (Nicholls, 1984; Dweck & Leggett, 1986). On the other hand, those with performance achievement goals are less likely to choose challenging tasks when alone and might change their challenge-seeking behaviours (to the direction compatible with their math self-concept) after evaluating the behaviours of others (Nicholls, 1984; Dweck & Leggett, 1986). Therefore, there is a possibility that the differences in achievement goals adopted by the participants regulated the extent to which participants would be susceptible to the social contagion of challenge-seeking. Another experiment was designed to address this possibility.

Furthermore, it was possible that the accuracy values of the pie charts discouraged participants from seeking challenges. Previous research suggested that individuals were likely to seek optimal challenges (Csikszentmihalyi & Larson, 2014; Ryan & Deci, 2020) that provided opportunities for learning (Gottlieb et al., 2013). Going after word problems with 2% success rate might have frightened the participants, as they were neither math professors nor had a specific interest in maths. Similarly, choosing very easy tasks (such as a word problem with 95% accuracy) might have been considered boring (Vygotsky, 1978). Rather than seeing the easier word problem as a safe option, they might have thought it would be too boring. Therefore, less extreme accuracy values were used in the following experiment (Experiment 3).

2.4. Experiment 3

The aim of this experiment was to investigate if achievement goals and/or trait intrinsic motivation played a role in participants' susceptibility to the social contagion of challenge-seeking. Literature in achievement motivation suggested that individuals with mastery-approach goals usually seek challenges for skill improvement, while those with performance-approach goals seek challenges in the presence of others (Nicholls, 1984; Ames & Archer, 1988; Dweck &Leggett 1988; Elliot & Harackiewicz, 1996). Therefore, challenge-seeking tendencies must be different in those with mastery approach goals and those with performance-approach goals before social factors come into play (the experimental manipulation). Furthermore, participants with performance achievement goals (both performance approach and performance avoidance goals) were suggested to pay more attention to social cues. For instance, Dweck (1986) claimed that they form their self-competence beliefs compared to those of others. Moreover, they showed greater vulnerability to negative feedback (Lee & Kim, 2014) and were motivated to compete and outperform others (Elliot & Harackiewicz, 1996). Butler (1992) indicated that those with higher mastery approach goals focused on learning more about the task while those with higher performance approach goals focused on comparing their scores to others'.

Two hypotheses were defined for Experiment 3. Hypothesis 1 was concerned with the replication of the social contagion of challenge-seeking behaviour observed in the first two experiments and Hypothesis 2 was defined regarding the relationship between the social contagion of challenge-seeking, achievement goals and trait motivation.

Hypothesis 1: Participants' challenge-seeking tendencies can be influenced by their perceptions of confederates' challenge-seeking behaviours. Based on the hypothesis, the following predictions were made:

1. Participants' baseline preference for difficult word problems would increase after observing the challenge-seeker confederate.
2. Participants' baseline preference for difficult word problems would decrease after observing the challenge-avoider confederate.
3. Participants' preference for difficult word problems after observing the challenge-seeker confederate would be greater than their preference for difficult word problems after observing the challenge-avoider confederate.

Hypothesis 2: Susceptibility to the social contagion of challenge-seeking behaviour is linked to one's achievement goal orientation and trait motivation. It was predicted that,

1. Mastery-approach goals would be linked to overall greater challenge-seeking.
2. Performance-approach goals would be associated with an increase in challenge-seeking behaviours after observing the challenge-seeker confederate.
3. Trait motivation scores would be linked to a greater amount of difficult word problem selections.

2.4.1. Method

2.4.1.1. Participants

84 (49 females, 3 other) participants were recruited using Prolific. The sample size was pre-determined based on the study budget. Participants' age range was between 18 to 36 and the mean age of the population was 22.69 (SD = 5.31). Their mean math anxiety score was 2.00 (SD = 1.11) out of 6. Sensitivity analysis (performed using G*Power 3.1.9.7, with a significance level (α) of .05, a power of .80) indicated a minimal statistically detectable effect size of 0.31 (dz).

Participants were screened for statistical analysis using the same criteria set in Experiment 1 (confederate plausibility and prediction accuracy). 13 participants (8 females, 1 other) were excluded due to confederate plausibility. 7 participants (5 females) were excluded for incorrectly predicting the challenge-seeking tendencies of the confederates. Two more participants were excluded from the statistical analysis for experiencing technical issues during the experiment.

The remaining population had 62 participants (36 females) with an age range between 18 to 36. (M = 21.95, SD = 3.67). Mean math anxiety was 2.13 (SD = 1.02) out of 6. Excluded participants' age (M = 24.77, SD = 8.13) and gender were not significantly different from the included participants' age, $t(24.10) = 1.57$, $p = .129$, d = 0.45 and gender, $x^2(1, N = 81) = 0.00$, $p = 1.00$. Excluded participants' mean math anxiety score (M = 1.63, SD = 1.29) was significantly lower than the included participants mean math anxiety score, $t(30.71) = 4.91$, $p < .001$, $d = 1.28$.

2.4.1.2. Experimental Procedure

The experimental procedure was similar to the ones used in Experiments 1 and 2 except for the following features:

- Example word problems presented at the instruction phase were removed.
- The surveys (all except the manipulation check survey) were administered before the challenge-seeking task.

Challenge-Seeking Task: The following modifications were made to the challenge-seeking task used in Experiment 2 (Figure 7):

- Accuracy percentage ranges used in easy and difficult settings were replaced with less extreme values. Easy category range of 78-98% was replaced with 61-81% and difficult category range of 2-22% was replaced with 19-39%. The medium category stayed at the 40-60% range. As the easy and difficult accuracy values became closer to medium category accuracy values, some trials asked participants to select between two word problems with very similar accuracy levels (e.g., 39% vs 40%). Since choosing 39% accuracy over 40% accuracy might not be confidently defined as a challenge-seeking behaviour, pairs of pie charts with accuracy differences less than 5% were not used in the task.
- The number of confederate incongruent trials was reduced to 3 out of 18 trials.

2.4.1.3. Surveys and Additional Tasks

At the end of the challenge-seeking task, participants solved five word problems. These word problems were the same as the ones used in Experiments 1 and 2. After each word problem, they were requested to rate their enjoyment in addition to rating their confidence in their answer, curiosity for the answer and perceived difficulty of the word problem. Participants' performance in these word problems was not subjected to statistical analysis.

Before the challenge-seeking task, participants' achievement goals, trait intrinsic motivation, math anxiety and math self-concept were measured.

Achievement goals were measured using a 2 x 2 Achievement Goal Questionnaire with four subscales: mastery-approach ("I want to learn as much as possible…"), mastery-avoidance ("I worry that I may not learn all that I possibly could…"), performance-approach ("It is important for me to do better than others"), and performance-avoidance ("I just want to avoid doing poorly…") (Elliot & McGregor, 2001) which was adapted to fit the contents of the challenge-seeking task (e.g., replaced words related to lecture, class with "word problems"). Subscale items had acceptable reliabilities (Cronbach's α for mastery-approach, mastery-avoidance, performance-approach, and performance-avoidance were .80, .74, .70, and .55, respectively). Participants reported their ratings on a 7-point scale, ranging from "not at all true of me" (1) to "very true of me" (7) (Appendix E.1.). Ratings within each subscale were averaged to create four achievement indices: mastery-approach index, mastery-avoidance index, performance-approach index, and performance-avoidance index.

Trait intrinsic motivation was measured using 12 items gathered from the three intrinsic motivation subscales of Global Motivation Scale. These subscales were motivation to know (i.e., In general I do things because I like making interesting discoveries), motivation towards accomplishment (i.e., In general I do things for the pleasure I feel mastering what I am doing), and motivation to experience stimulation (i.e., In general I do things in order to feel pleasant emotions) (Guay et al., 2003). Subscale items had good reliabilities (Cronbach's α for "to know", "towards accomplishment", and "to experience stimulation" were .85, .74 and .86 respectively). Participants reported their ratings on a 7-point scale ranging from "does not correspond" (1) to "corresponds completely" (7) (Appendix E.2.); and three intrinsic motivation indices were created by averaging the ratings for each subscale: knowledge index, accomplishment index, and stimulation index.

After the word problem-solving session, participants were requested to complete the manipulation check survey which was identical to the one used in Experiment 2.

2.4.2. Results

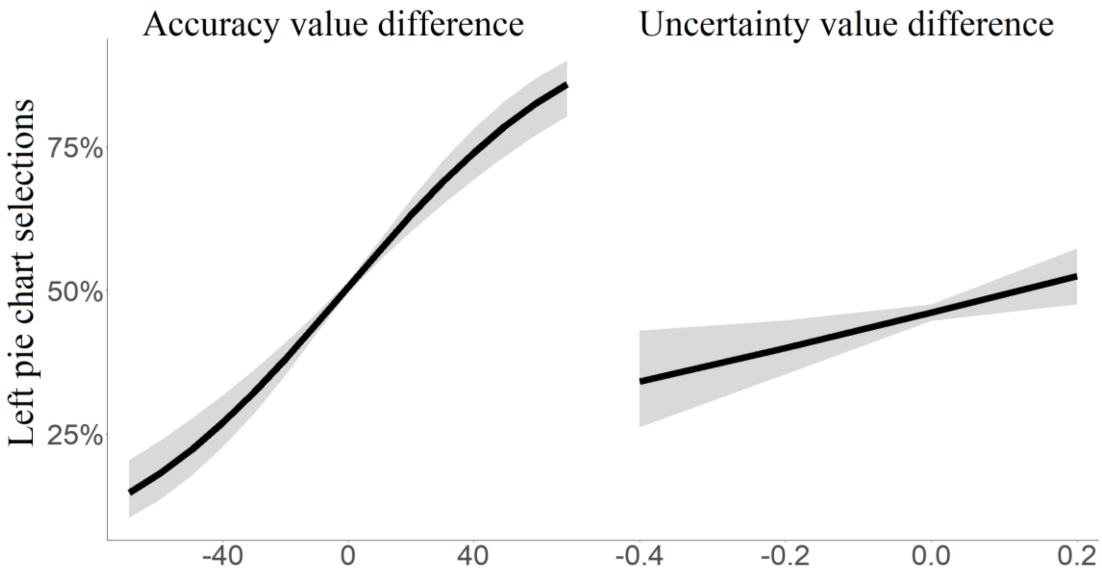
2.4.2.1. Participants' Challenge-Seeking at Baseline

Consistent with the first 2 experiments, participants generally avoided challenging word problems. Their challenge-seeking rates at baseline was .22 (*SD* = .26), higher than the one observed in Experiment 2 (*M* = .18, *SD* = .25), but lower than the one observed in Experiment 1 (*M* = .30, *SD* = .31).

A mixed-effects logistic regression model predicting word problem selection by the accuracy and entropy differences between the left and right pie charts replicated the results reported in Experiments 1 and 2. Participants were less likely to seek challenges as accuracy the difference between the word problems increased, β = 0.03, *SE* = 0.003, 95% *CI* [0.02, 0.03], *p* = <.001, and more likely to choose the word problem with higher entropy value as the difference between the options' entropy values increased, β = 1.26, *SE* = 0.48, 95% *CI* [0.33, 2.19], *p* = .008 (Figure 10).

Figure 10

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

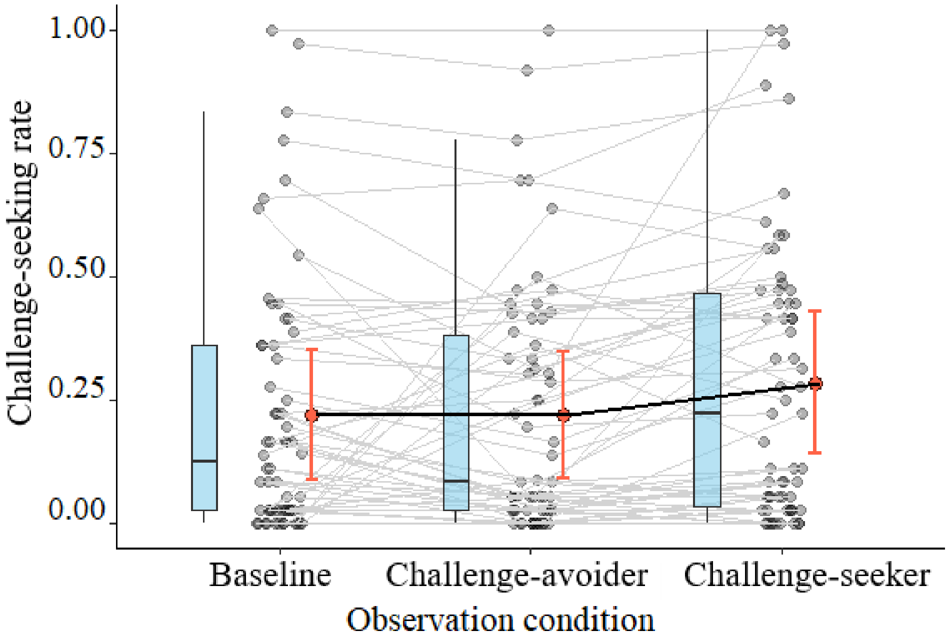
2.4.2.2. Social Effects of Confederates' Choices on Participants' Challenge-Seeking

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA revealed a significant main effect of observation condition, $F(1.77, 106.31) = 5.67$, $p = .006$, $\eta_G^2 = .01$. Participants had significantly different challenge-seeking rates at baseline ($M = 0.22$, $SD = 0.26$), in challenge-seeker ($M = 0.28$, $SD = 0.28$) and in challenge-avoider conditions ($M = 0.22$, $SD = 0.25$). Confederate order did not contribute to the change in challenge-seeking rates; $F(1, 60) = 0.12$, $p = .746$, $\eta_G^2 = .002$. Challenge-seeking rates did not change across those who observed the challenge-seeker confederate first ($M = 0.25$, $SD = 0.29$) and those who observed the challenge-avoider confederate first ($M = 0.23$, $SD = 0.24$). The interaction effect of confederate order and observation condition on challenge-seeking rates was not significant, $F(1.77, 106.31) = 1.62$, $p = .206$, $\eta_G^2 = .004$.

Paired samples *t*-tests showed significantly greater challenge-seeking rates in the challenge-seeker condition compared to the challenge-avoider condition; $t(61) = 3.52$, $p < .001$, $dz = 0.45$ (Holm adjusted alpha level = .02), and compared to the baseline condition, $t(61) = 2.63$, $p = .011$, $dz = 0.33$, Holm corrected alpha level = .03. Challenge-seeking rates did not significantly differ between baseline and the challenge-avoider condition, $t(61) = 0.03$, $p = .977$, $dz = 0.00$, Holm corrected alpha level = .05 (Figure 11).

Figure 11

Challenge-seeking rates in Experiment 3 for each observation condition



Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition were demonstrated with red dots and connected with dark black lines.

2.4.2.3. Relationship Between Achievement Goals and Challenge-Seeking Behaviours

Baseline challenge-seeking was not correlated with participants' mastery-approach goal scores ($r = -.07$, $t(60) = 0.58$, $p = .567$), mastery-avoidance goal scores ($r = -.04$, $t(60) = 0.28$, $p = .782$), performance-approach goal scores ($r = .10$, $t(60) = 0.81$, $p = .423$) or performance-avoidance goal scores ($r = -.10$, $t(60) = 0.78$, $p = .440$).

Based on the proposed role of perceived ability on challenge-seeking tendencies of those with performance achievement goals (Nicholls, 1984; Dweck, 1986; Ames &

Archer, 1988), a correlation analysis between participants' math self-concept scores and their performance achievement goal scores was conducted. Math self-concept scores were not correlated with participants' performance-approach goal scores, r = .19, t(60) = 1.50, p = .138. or their performance-avoidance goal scores, r = .27, t(60) = 2.15, p = .03 (Bonferroni adjusted alpha value is 0.05/2).

The behavioural shift across challenge-seeker and challenge-avoider conditions was positively correlated with participants' self-reported mastery-approach goals and their trait intrinsic motivation scores, particularly the 'motivation to know' subscale (Table 1). Participants' mastery-approach goals were also positively correlated with the behavioural shift between the challenge-seeker and baseline conditions. Other types of achievement goals were not significantly correlated with the change in challenge-seeking behaviours.

2.4.2.4. Exploratory Analyses

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA did not indicate a significant effect of observation condition, $F(2, 120) = 0.22$, $p = .802$, $\eta_G^2 = .001$, confederate order, $F(1, 60) = 1.23$, $p = .273$, $\eta_G^2 = .01$, or their interaction, $F(2, 120) = 2.37$, $p = .098$, $\eta_G^2 = .01$, on the uncertainty resolution behaviour. Therefore, observed behavioural shift was not associated with uncertainty resolution behaviour.

Additional exploratory analysis showed that participants' age, gender, math anxiety and math self-concept scores were not correlated with the change in their challenge-seeking behaviours across observation conditions (Appendix B).

Table 1

Pearson correlation results investigating the correlation between participant demographics, self-rated math skills, intrinsic motivation & achievement goals and the shift in challenge-seeking rate across observation conditions.

Difference between observation conditions	Variable	r	t	df	p

Baseline - Seeker	Math self-concept	-.09	0.67	60	.507
	Math anxiety	.10	0.78	60	.437
	Mastery-approach	.28	2.25	60	.028*
	Mastery-avoidance	.12	0.92	60	.361
	Performance-approach	.07	0.52	60	.602
	Performance-avoidance	.15	1.21	60	.231
	t-IM - knowledge	.24	1.94	60	.058
	t-IM - accomplishment	.13	1.05	60	.298
	t-IM - stimulation	.18	1.43	60	.157
Baseline - Avoider	Math self-concept	-.01	0.11	60	.917
	Math anxiety	.15	1.15	60	.254
	Mastery-approach	.16	1.24	60	.219
	Mastery-avoidance	.18	1.38	60	.173
	Performance-approach	-.10	0.74	60	.461
	Performance-avoidance	.07	0.54	60	.592
	t-IM - knowledge	.03	0.26	60	.793
	t-IM - accomplishment	-.01	0.09	60	.932
	t-IM - stimulation	.07	0.56	60	.580
Seeker - Avoider	Math self-concept	.09	0.67	60	.504
	Math anxiety	.10	0.78	60	.438
	Mastery-approach	.26	2.07	60	.042*

Mastery-avoidance	.23	1.82	60	.073
Performance-approach	.05	0.37	60	.710
Performance-avoidance	.15	1.14	60	.256
t-IM - knowledge	.27	2.21	60	.031*
t-IM - accomplishment	.22	1.74	60	.087
t-IM - stimulation	.16	1.27	60	.211

Note. "Seeker" = challenge-seeker condition, "avoider" = challenge-avoider condition. "t-IM" stands for Trait Intrinsic Motivation Scale. It had three subscales: (1) intrinsic motivation to know (t-IM - knowledge), (2) intrinsic motivation to accomplish (t-IM - accomplishment) and (3) intrinsic motivation for stimulation (t-IM - stimulation). "*" is used to emphasise *p* values smaller than 0.05.

2.4.3. Conclusions

The social contagion of challenge-seeking behaviour observed in Experiments 1 and 2 was replicated in Experiment 3 as well. Participants increased their challenge-seeking behaviours after observing the challenge-seeker while their challenge-seeking behaviours were unaffected by the observation of the challenge-avoider confederate.

Obtained correlations between achievement goals and the social contagion of challenge-seeking behaviour confirmed the hypothesis that achievement goals are related to the social contagion of challenge-seeking behaviours. However, results did not support for the predicted link between performance achievement goals and susceptibility to the social contagion of challenge-seeking, even after controlling for the effect of participants' perceived self-concept scores. Instead, mastery-approach goals and trait motivation scores were positively correlated with the social contagion of challenge-seeking behaviour.

Additionally, participants' achievement goals and trait motivation scores were not significantly associated with their overall challenge-seeking. Therefore, Experiment 3 could not find evidence that individuals with mastery-approach goals engaged in challenge-seeking behaviour more frequently, or that individuals with performance-avoidance goals avoided challenging tasks. However, this result must be approached with caution. Previous studies indicating fewer challenge-seeking behaviours in those with performance-avoidance goals either reported this tendency after participants encountered a failure (Kuhl & Blankenship, 1979; Lee & Kim, 2014) or when they were encouraged to adopt performance achievement goals (e.g., experimentally induced state of ego-involvement) (McClelland et al., 1949; Jagacinski et al., 2008).

There is a possibility that the observed shifts in challenge-seeking behaviours are related to a change in participants' perceived difficulty of the word problems or to an increase in their self-confidence in correctly answering them. To test these explanations, another experiment was designed to compare participants' ratings of self-confidence and perceived difficulty across observation conditions.

2.5. Experiment 4

The aim of Experiment 4 was to investigate whether the behavioural shift in challenge-seeking rates observed in the previous experiments resulted from the social contagion of challenge-seeking, or a change in participants' perceived ability or perceived difficulty of the word problems. Specifically, after observing the challenge-seeker confederate, participants might have thought that the word problems were not as difficult as they initially believed, or they were as capable as the confederate in solving hard word problems. Such adjustment in perception might have encouraged participants to select difficult word problems more frequently.

Considering this possibility, in addition to the replication of the previous findings (Hypothesis 1) a second hypothesis was defined which suggested that the observed shift in behavioural tendency is not related to a change in perceived difficulty of the word problems and/or participants' self-confidence in successfully solving hard word problems.

Hypothesis 1: Participants' challenge-seeking tendencies can be influenced by their perceptions of confederates' challenge-seeking behaviours. Based on the hypothesis, the following predictions were made:

1. Participants' baseline preference for difficult word problems would increase after observing the challenge-seeker confederate.

2. Participants’ baseline preference for difficult word problems would decrease after observing the challenge-avoider confederate.
3. Participants’ preference for difficult word problems after observing the challenge-seeker confederate would be greater than their preference for difficult word problems after observing the challenge-avoider confederate.

Hypothesis 2: Observation of confederates’ challenge-seeking/avoiding behaviours leads to the adoption of these behaviours, possibly without being mediated by any change in task- or self-perception. Based on Hypothesis 2, it was predicted that,

1. Participants’ perceived difficulty or self-confidence ratings for the difficult word problem would not change across observation conditions.

2.5.1. Method

2.5.1.1. Participants

77 participants (50 females) were recruited using Prolific. The sample size was pre-determined based on the study budget. Participants’ age range was between 18 to 49 and the mean age of the population was 25.12 (*SD* = 6.54). Their mean math anxiety scores were 2.68 (*SD* = 1.38) out of 6. Sensitivity analysis (performed using G*Power 3.1.9.7, with a significance level (α) of .05, a power of .80) indicated a minimal statistically detectable effect size of 0.32 (*dz*).

22 participants (11 females) were excluded from the statistical analysis due to the exclusion criterion on doubting confederate plausibility (set in Experiment 1). 5 participants (2 females) incorrectly predicted the challenge-seeking tendencies of the confederates and therefore excluded from the statistical analysis (second exclusion criterion set in Experiment 1). The remaining population had 50 participants (37 females) with an age range between 18 to 49 and the mean age of 24.62 (*SD* = 5.93). Their mean math anxiety score was 2.78 (*SD* = 1.43) out of 6. Excluded participants’ age (*M* = 26.04, *SD* = 7.58), gender and math anxiety scores (*M* = 2.48, *SD* = 1.28) were not significantly different from the included participants’ age, *t*(43.54) = 0.84, *p* = .404, *d* = 0.21; gender: x^2(1, *N* =77) = 4.07, *p* = .043, or math anxiety: *t*(58.72) = 0.93, *p* = .354, *d* = 0.22.

2.5.1.2. Experimental Procedure

The experimental procedure was similar to Experiments 3 except for the changes in the challenge-seeking task, and the exclusion of word problem-solving session and surveys (other than the demographic information survey).

Challenge-Seeking Task: The following modifications were made to the challenge-seeking task (Figure 7) that was used in Experiment 3:

- The number of confederate incongruent trials was reduced to 2 out of 18 trials (as it was in Experiment 1).
- In 1/6 of make-your-choice trials, participants' perceived difficulty and perceived self-confidence ratings were collected for each pie chart. These ratings appeared in a Likert scale format below each pie chart right after the participant selected a word problem (Figure 12). Presentation of these scales were counterbalanced. In half of the trials, the Likert scale under the chosen pie chart appeared first; in the other half, the Likert scale under the not-chosen pie chart appeared first. When participants provided rating for each pie chart, they clicked on the submission button placed under the Likert scale. These scales were only added to make-your-choice trials (Sessions 1, 3 and 5) and did not have a time limit.

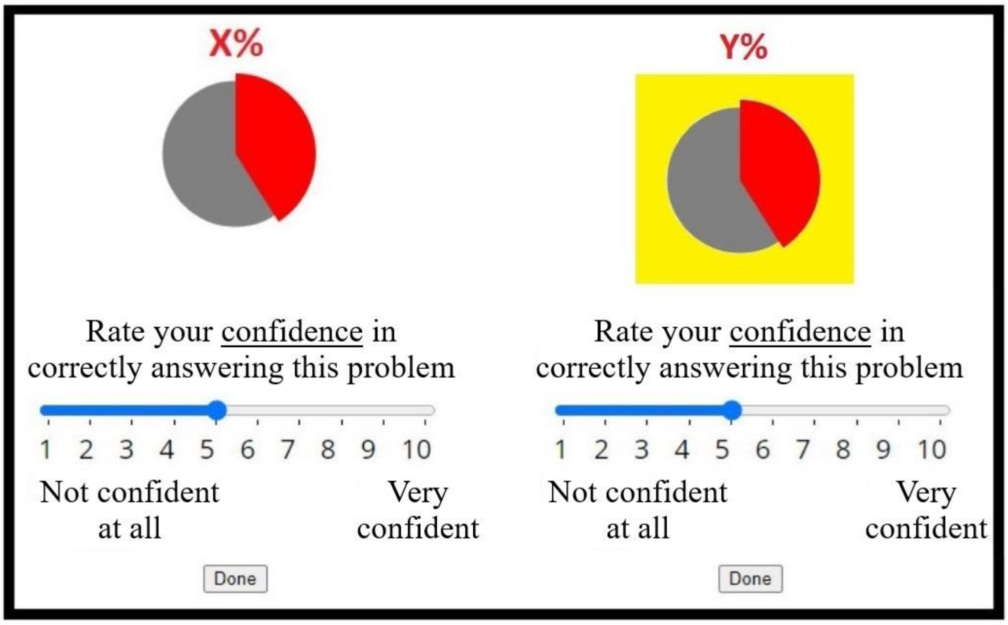
2.5.1.3. Surveys

Participants' math anxiety scores were measured in the demographic information survey. After the challenge-seeking task, participants were requested to complete the manipulation check survey. The survey was identical to the one used in Experiment 2.

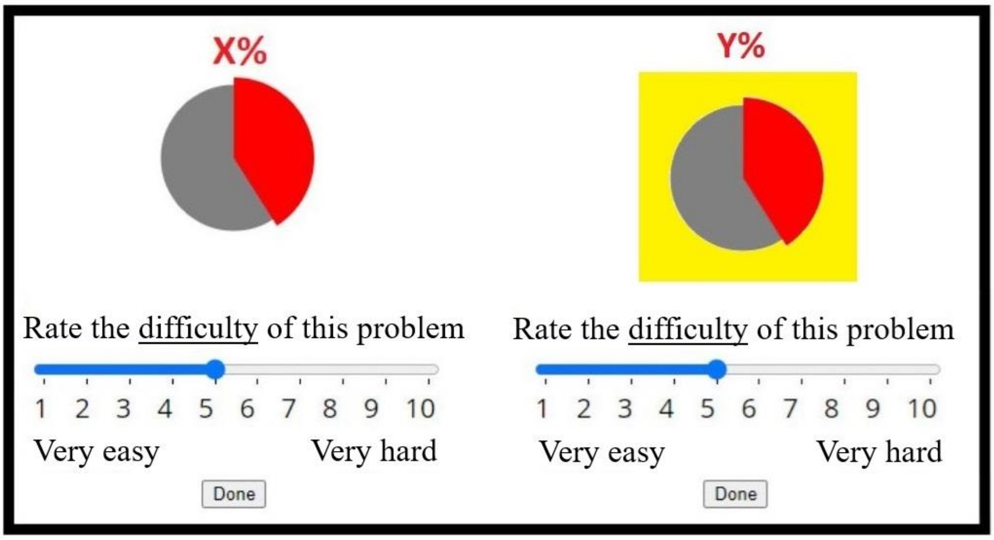
Figure 12

Self-confidence and perceived difficulty ratings used in Experiment 4

A.



B.



Note. In 1/6 of the make-your-choice trials, participants rated their perceptions of (A) self- confidence and (B) word problem difficulty for both the pie chart they chose and the one they did not choose. The order of rating scale appearance was counterbalanced across rating type (self-confidence, word problem difficulty) and pie chart choice (chosen pie chart first, not-chosen pie chart first). Rating phase did not have a time limit.

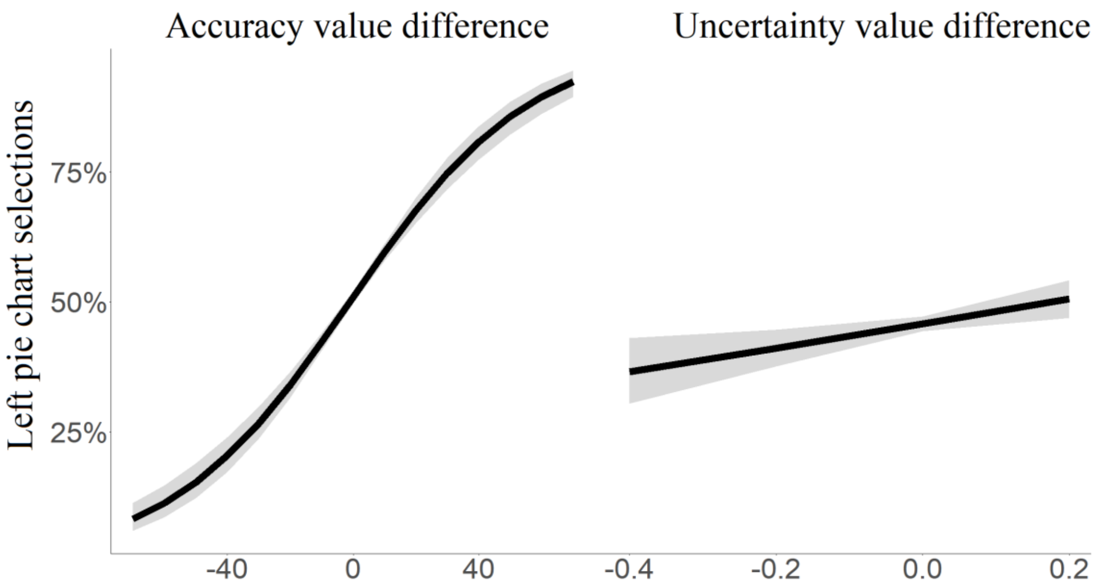
2.5.2. Results

2.5.2.1. Participants' Challenge-Seeking at Baseline

Participants showed a challenge-avoiding tendency at baseline (*M* = .12, *SD* = .20). A mixed-effects logistic regression model predicting word problem selection by the accuracy and entropy difference between the two word problems showed a decrease in the choice of harder word problems with the increase between the pie charts' accuracy values, $\beta = 0.03$, *SE* = 0.003, 95% *CI* [0.03, 0.04], $p < .001$, and an increase in choice of high entropy option as the difference between the options' entropy values increased β = 0.96, *SE* = 0. 34, 95% *CI* [0.29, 1.62], *p* = .005 (Figure 13).

Figure 13

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



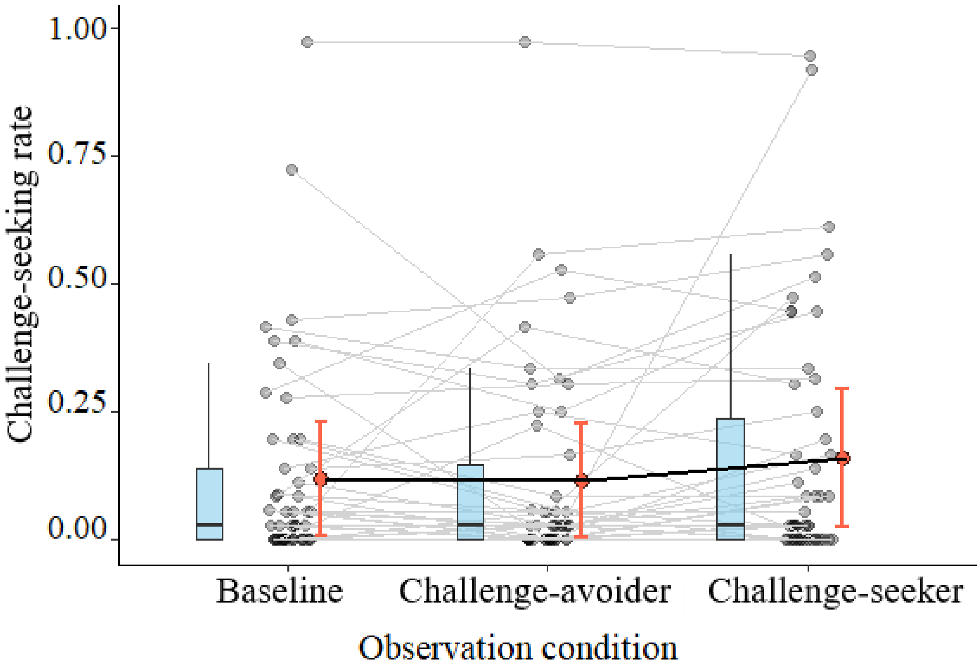
Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

2.5.2.2. Social Effects of Confederates' Choices on Participants' Challenge-Seeking

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA indicated a non-significant main effect of observation condition, $F(2, 96) = 2.62$, $p = .078$, $\eta_G^2 = .01$, confederate order, $F(1, 48) = 0.63$, $p = .432$, $\eta_G^2 = .01$, and the interaction between confederate order and observation condition, $F(2, 96) = 1.24$, $p = .294$, $\eta_G^2 = .004$, on challenge-seeking rates (Figure 14).

Figure 14

Challenge-seeking rates in Experiment 4 for each observation condition



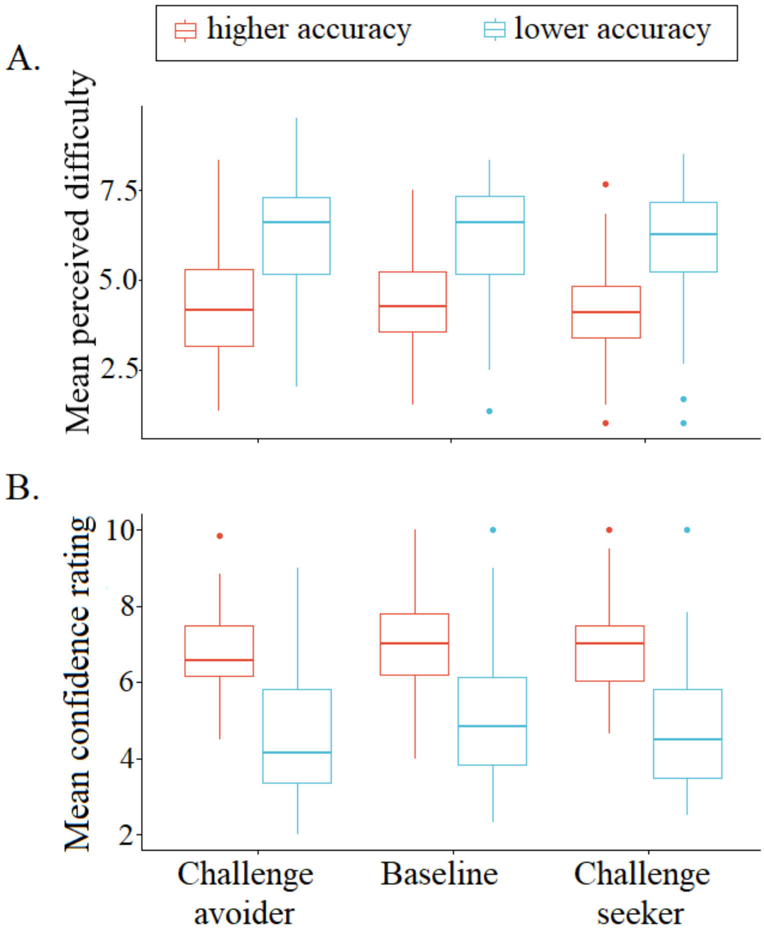
Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition were demonstrated with red dots and connected with dark black lines.

2.5.2.3. Changes in Self-Confidence and Perceived Difficulty of Word Problems

Participants' ratings of self-confidence and perceived difficulty across observation conditions using were compared using a 3 (observation condition: baseline, challenge-seeker, challenge-avoider) by 2 (word problem difficulty: low accuracy, high accuracy) repeated measures ANOVA analysis. As expected, participants' perceived difficulty was greater for the harder word problems, $F(1, 49) = 57.07$, $p < .001$, $\eta_G^2 = .26$, $t(149) = 11.50$, $p < .001$, $dz = .94$, and their self-confidence ratings were significantly greater for the easier word problems, $F(1, 49) = 114.04$, $p < .001$, $\eta_G^2 = .33$, $t(149) = 16.26$, $p < .001$, $dz = 1.33$ (Figure 15). Importantly, neither their perceived difficulty, $F(2, 98) = 0.83$, $p = .441$, $\eta_G^2 = .002$, nor their self-confidence reports significantly changed across observation conditions, $F(1.63, 79.87) = 2.43$, $p = .105$, $\eta_G^2 = .01$. Also, there were no significant interaction effects between their perceived difficulty ratings and observation conditions, $F(1.76, 86.24) = 0.75$, $p = .460$, $\eta_G^2 = .001$, and their self-confidence and observation conditions, $F(2, 98) = 0.49$, $p = .616$, $\eta_G^2 = .001$ (please refer to Table 2 for mean and SD values of each group).

Figure 15

Perceived difficulty and confidence ratings for higher accuracy and lower accuracy word problems across observation conditions



Note. For each pair of word problems presented in a single trial (A) pie charts with lower accuracy were rated as more difficult than the ones with higher accuracy ones and (B) participants reported less confidence in successfully solving the word problems they represented.

Table 2

Mean and SD values of participants' self-confidence and their perceived difficulty ratings of easier and harder pie charts aggregated for each observation condition

Observation condition	Problem difficulty	Self-confidence		Perceived difficulty	
		M	*SD*	*M*	*SD*
Baseline	Easier	7.03	1.14	4.42	1.29

	Harder	5.10	1.73	6.08	1.64
Challenge-avoider	Easier	6.82	1.11	4.31	1.47
	Harder	4.75	1.84	6.16	1.78
Challenge-seeker	Easier	6.90	1.21	4.12	1.36
	Harder	4.81	1.59	6.06	1.64

Note. "Easier" and "harder" word problems were defined in a relative term. Specifically, for each pair of options, the option with lower accuracy was defined as the "harder" word problem whereas the option with higher accuracy was defined as the "easier" one.

2.5.2.4. Exploratory Analyses

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA did not indicate a significant effect of observation condition, $F(2, 96) = 0.56$, $p = .576$, $\eta_G^2 = .01$, confederate order, $F(1, 48) = 2.51$, $p = .120$, $\eta_G^2 = .03$, or their interaction, $F(2, 96) = 0.54$, $p = .583$, $\eta_G^2 = .01$, on participants' uncertainty resolution behaviours. Therefore, it is unlikely that the observed behavioural shift across observation conditions is related to uncertainty resolution behaviour.

A paired samples *t*-test was conducted to compare participants' mean reaction times before and after the rating trials. This was done to investigate the effects of task switching on participants' cognitive load. Participants' response speed decreased significantly in the trials that followed the rating trials ($M = 1516.68$ milliseconds, $SD = 784.91$) compared to the ones that preceded the rating trials ($M = 1273.53$ milliseconds, $SD = 724.63$), $t(49) = 5.96$, $p < .001$, $dz = .84$.

Participants' age, gender, or math anxiety were not significantly correlated with the changes in their challenge-seeking behaviours across observation conditions (Appendix B).

2.5.3. Conclusions

The results were consistent with the first 3 experiments regarding the null effect of observing the challenge-avoider confederate. However, the previously observed effect of challenge-seeker confederate was not replicated in Experiment 4. Although the trend was in the predicted direction, the difference in challenge-seeking rates across the observation conditions was not significant. It is possible that the perceived difficulty and self-confidence ratings that were superimposed on the challenge-seeking task introduced an extra cognitive load and prevented participants from giving their full attention to the challenge-seeking task. 18 out of 108 trials included perceived difficulty and self-confidence ratings and the appearance of these trials were randomised. Increased reaction times to select a word problem in trials that followed perceived difficulty and self-confidence ratings supported the possible interference of task switching.

Importantly, participants' perceived difficulty or self-confidence ratings for the word problems did not significantly change across the observation conditions. Although the challenge-seeker confederate's behaviours were not adopted as expected, current results did not indicate a mediation effect of task- or self-perception on challenge-seeking behaviours either. Therefore, the second hypothesis is partly supported.

In the last four experiments, the parameters of the challenge-seeking task were fine-tuned (e.g., accuracy values) and the effect of participants' beliefs and orientation on their proneness to experience the social contagion of challenge-seeking were investigated. However, they all had a limitation of not being pre-registered. Their sample sizes were only determined by the study budget, although defined prior to data collection. The predictions of the experiment, the statistical analyses to be conducted were not pre-registered. In order to resolve it, one last experiment (Experiment 5) was conducted with a larger sample size.

2.6. Experiment 5

This experiment was conducted to confirm the results obtained from the first four experiments with a pre-registration. For this purpose, the description of hypotheses, predictions, data collection procedures, and an analysis plan was predefined. The sample size was predetermined using power calculations. Importantly, this experiment did not employ the features that previous four experiments found unrelated to the social contagion of challenge-seeking behaviour (e.g., perceived difficulty ratings). This version was also intended to be used as a pilot experiment for the planned fMRI experiment (explained in detail in Chapter 4). Since this was a confirmatory experiment, the hypothesis and the predictions regarding the influence of observing a challenge-seeker was defined based on the consistently observed result of the first four experiments.

Hypothesis: Participants' challenge-seeking tendencies would be influenced by their perceptions of confederates' challenge-seeking behaviours. Based on the hypothesis, the following predictions were made:

1. Participants' baseline preference for difficult word problems would increase after observing the challenge-seeker confederate.
2. Participants' baseline preference for difficult word problems would decrease after observing the challenge-avoider confederate.
3. Participants' preference for difficult word problems after observing the challenge-seeker confederate would be greater than their preference for difficult word problems after observing the challenge-avoider confederate.

2.6.1. Method

2.6.1.1. Participants

149 participants (82 females) were recruited. Sample size was determined by power calculation (using $\alpha = .05/3$, power = .80, the effect size from one-sample *t*-test in Experiment 3 = 0.45) and study budget. The pre-registration of the experiment can be found at "osf.io/6cgwh". The population age ranged from 18 to 50 and the mean age was 24.16 (*SD* = 5.29). Mean self-reported math-anxiety score was 2.49 (*SD* = 1.22) out of 6.

Based on the participant screening criteria set in Experiment 1, 31 participants (15 females, 1 other) were excluded from the analysis due to doubting confederate plausibility, and 7 participants (3 females) were excluded from the analysis for not correctly predicting the challenge-seeking tendencies of the confederates. The resulting final sample had 111 participants (63 females, 3 other) with a mean age of 23.70 (*SD* = 4.83), an age range of 18 - 50 and a mean math anxiety score of 2.46 (*SD* = 1.23) out of 6. Excluded participants' age (*M* = 25.50, *SD* = 6.34), gender and math anxiety (*M* = 2.56, *SD* = 1.23) characteristics were not significantly different from the included ones (age: $t(52.45) = 1.60$, $p = .117$, $d = 0.32$, math anxiety: $t(63.95) = 0.46$, $p = .647$, $d = 0.09$ and gender: $x^2(1, N = 145) = 0.69$, $p = .405$).

2.6.1.2. Experimental Procedure

The experimental procedure was similar to the one used in Experiment 4 (Figure 7) except for the perceived difficulty and self-confidence ratings used in the make-your-choice trials.

2.6.1.3. Surveys

Item measuring participants' math anxiety was added to the demographic information survey (used in Experiments 1-4). After the challenge-seeking task, participants were requested to complete the manipulation check survey, which was identical to the one used in Experiment 2.

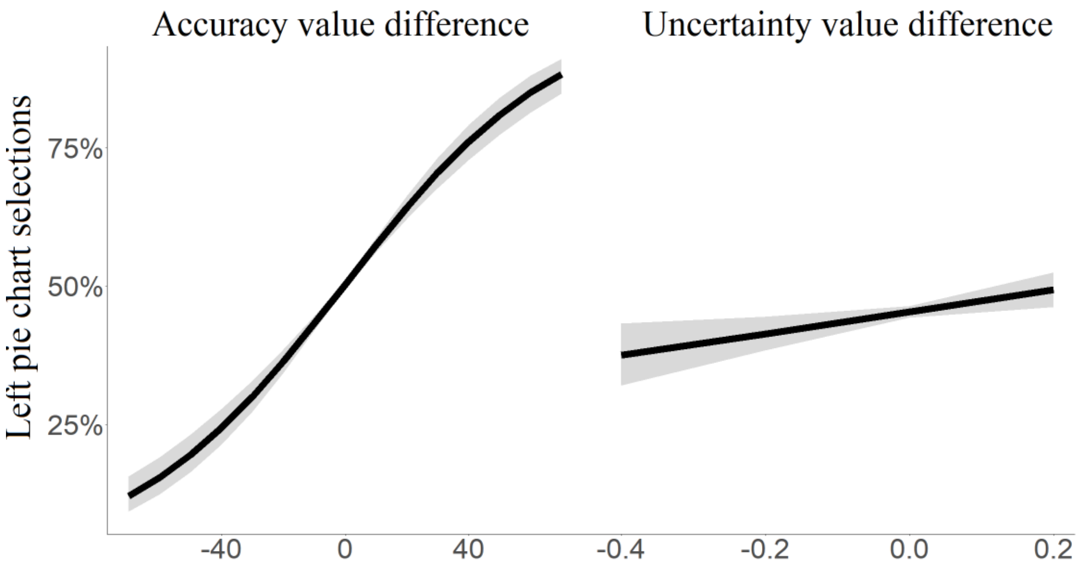
2.6.2. Results

2.6.2.1. Participants' Challenge-Seeking at Baseline

At baseline, participants' challenge-seeking rate was 0.19 (*SD* = .25). A mixed-effects logistic regression model predicting word problem selection by the accuracy difference between the two word problems showed a decrease in the choice of harder word problems with the increase between the pie charts' accuracy values, $\beta = 0.03$, *SE* = 0.002, 95% *CI* [0.02, 0.03], $p < .001$. Furthermore, participants were more likely to select the higher entropy option as the difference between the pie charts' entropy values increased, $\beta = 0.81$, *SE* = 0.30, 95% *CI* [0.22, 1.40], $p = .007$ (Figure 16).

Figure 16

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



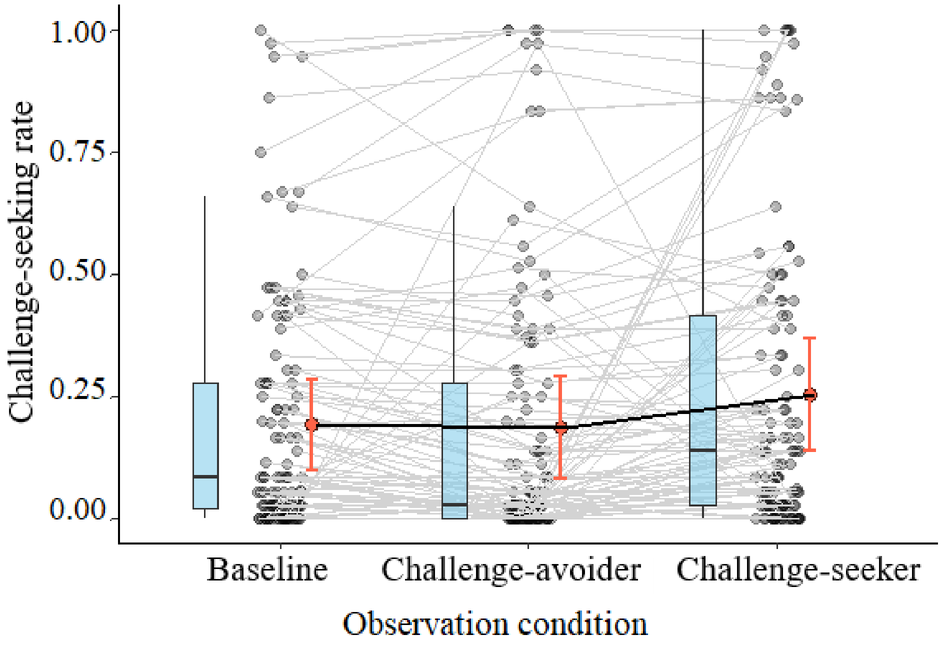
Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

2.6.2.2. Social Effects of Confederates' Choices on Participants' Challenge-Seeking

A 3 (observation condition: baseline, challenge-seeker, challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA showed a significant main effect of observation condition, $F(1.67, 181.63) = 6.78$, $p = .003$, $\eta_G^2 = .01$. Individual paired samples *t*-tests showed significantly greater challenge-seeking rates in the challenge-seeker condition ($M = 0.26$, $SD = 0.30$) compared to both the challenge-avoider ($M = 0.19$, $SD = 0.28$), $t(110) = 2.90$, $p = .004$, $dz = 0.28$ (Holm adjusted alpha level = .02), and the baseline conditions ($M = 0.19$, $SD = 0.25$), $t(110) = 2.88$, $p = .005$, $dz = .27$, Holm adjusted alpha level = .03. Challenge-seeking rates in the challenge-avoider and baseline conditions were not significantly different, $t(110) = 0.33$, $p = .746$, $dz = .03$, Holm adjusted alpha level = .05. Confederate order, $F(1, 109) = 0.79$, $p = .375$, $\eta_G^2 = .01$ or the interaction between the observation conditions and the confederate order, $F(1.67, 181.63) = 1.43$, $p = .242$, $\eta_G^2 = .01$ did not significantly influence participants' challenge-seeking rates (Figure 17). These findings were consistent with the first four experiments and in support of the predictions suggesting that observing the challenge-seeker confederate would alter participants challenge-seeking behaviours while observing the challenge-avoider confederate would not influence it.

Figure 17

Challenge-seeking rates in Experiment 5 for each observation condition



Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition were demonstrated with red dots and connected with dark black lines.

2.6.2.3. Exploratory Analyses

A 3 (observation condition: baseline, challenge-seeker, and challenge-avoider) by 2 (confederate order: challenge-seeker first, challenge-avoider first) mixed ANOVA did not indicate a significant effect of observation condition, $F(1.84, 200.58) = 0.71$, $p = .482$, $\eta_G^2 = .002$, confederate order, $F(1, 109) = 2.36$, $p = .127$, $\eta_G^2 = .02$, or their interaction, $F(1.84, 200.58) = 0.99$, $p = .369$, $\eta_G^2 = .002$, on uncertainty resolution behaviour.

Furthermore, the changes in challenge-seeking behaviour across observation conditions were not correlated to participants age, gender or math anxiety scores (Appendix B).

2.6.3. Conclusions

As predicted, confirmatory analysis revealed that observing the challenge-seeker confederate led to an increase in difficult word problem selections. Although the participants did not select these hard problems as frequently as the confederate did, they were much more explorative in their word problem selections. Their challenge avoidant approach at baseline and after observing the challenge-avoider was slightly dampened after the observation of the challenge-seeker confederate. Crucially, the observed changes in participants' challenge-seeking behaviours were not motivated by uncertainty resolution behaviours and were not influenced by participants' demographic characteristics.

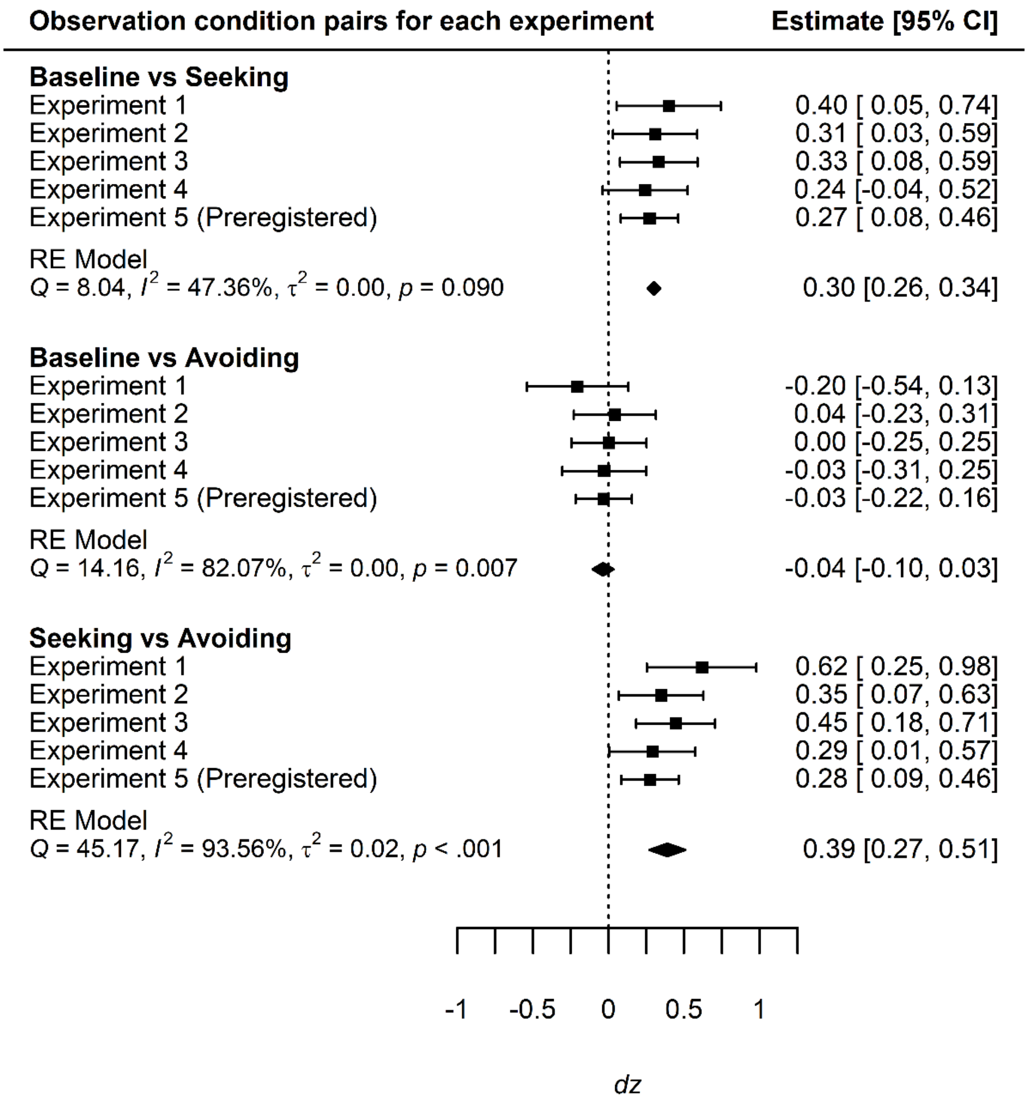
In order to test the accuracy of the observed effects and increase the statistical power a meta-analysis consisting of the effect sizes from each of the five experiments was conducted. The results are reported under the Integrated Results section.

2.7. Integrated Results

A meta-analysis consisting of the effect sizes of all five online experiments was conducted to get a more accurate effect size estimate. The forest plot is presented in Figure 18. The integrated effect size for the comparison between the challenge-seeker and challenge-avoider conditions was $dz = 0.39$, 95% $CI = [0.27, 0.51]$. The integrated effect size for the comparison between the challenge-seeker and baseline conditions was $dz = 0.30$, 95% $CI = [0.26, 0.34]$. The integrated effect size for the comparison between the challenge-avoider condition and baseline condition was $dz = -0.04$, 95% $CI = [-0.10, 0.03]$.

Figure 18

Forest plot of meta-analysis showing the difference between challenge-seeker, challenge- avoider and baseline conditions for all experiments



Note. Effect size and 95% confidence interval of paired comparison between challenge-seeker, challenge-avoider and baseline conditions for all experiments. Squares show effect estimates for each experiment and diamond shape shows the pooled effect estimate. Values on the bottom left corner show the test of heterogeneity.

Meta-analyses of four experiments with regard to the correlation between the 3 participant demographics (age, gender and math anxiety) and the shift in challenge-seeking behaviour across observation conditions indicated negligible pooled effect sizes (Appendices C1-C3).

2.8. Summary and Concluding Discussion

The majority of the behavioural experiments reported in this chapter indicated that observing a challenge-seeker individual would lead to a change in challenge-seeking behaviours of the observer. The only experiment that did not reveal this result was Experiment 4. However, as reported earlier, for one sixth of the trials, participants had to switch back and forth between rating and selecting word problems. Reduced challenge-seeking behaviour might be a result of the effect of frequent task switching on executive functions needed for the challenge-seeking task. Task switching may tax the working memory resources needed to hold the task relevant information and may reduce participants' attention to task specific elements (Vandierendonck et al., 2010). Significantly greater reaction times for the trials that followed the task switching trials provided support for this assumption. Furthermore, even though the difference was not significant, the predicted behavioural shift was observed in the descriptive statistics. Participants were more likely to select harder word problems in the challenge-seeker condition compared to the baseline and challenge-avoider conditions.

All five experiments indicated a tendency to choose the word problems for which success was uncertain. This was the result of an exploratory analysis in Experiment 1 and replicated in the following four experiments as well. Although not predicted, as it was not in the scope of the research question, this finding was not surprising. Curiosity has been previously associated with risky decision-making (Lau et al., 2020; FitzGibbon et al., 2020) and uncertainty resolution and exploration related behaviours (Gordon et al., 2015). Importantly, as consistently shown in all five experiments, participants' uncertainty resolution behaviours were not influenced by the social contagion manipulation.

Chapter 3: Agent Likeability in the Social Contagion of Challenge-Seeking

The aims of the current experiment were two-fold. The first one was to replicate the social contagion of challenge-seeking behaviour in face-to-face interactions to generalise the observed findings to real-life social interaction settings. The second, and more important aim was to investigate whether the feelings of likeability felt towards the confederate would modulate the degree to which the social contagion of challenge-seeking behaviour was experienced.

Agent likeability has been shown to facilitate the effects of social influence. For instance, previous research indicated that liked others' emotions were adopted easily (Hatfield et al., 1993; Wróbel & Królewiak, 2015) and agent likeability was linked to greater peer conformity (Gommans et al., 2017). On the other hand, disliked others had less social influence on others (Carli, 2001). Research particularly focused on the impact of social agent likeability on achievement motivation revealed that individuals shared similar motivational beliefs (Ryan, 2001), competence-related beliefs (Altermatt & Pomerantz, 2003), academic achievement (for a review, see Burgess et al., 2020), school grades (Gremmen et al., 2017), and homework activity and paying attention in class (Geven et al., 2013) as their friends, whom they liked. For instance, in schools, well-liked children influence their peers' academic norms and engagement (Lease et al., 2020).

Crucially, possible effects of likeability on the social contagion of challenge-seeking have not been examined yet. Only a longitudinal study conducted by Altermatt and Pomerantz (2003) indicated socially contagious challenge-seeking preferences. In their design, children's self-reports of challenge preferences were collected at three time points that were 6 months apart each and they showed similarity in the challenge preferences of close friends. Importantly, this study has not induced and manipulated likeability. Therefore, factors other than likeability may have contributed to this similarity in challenge-seeking preferences, such as having the same teacher. Moreover, children's challenge-seeking preferences were obtained using a self-report. Using a self-report as a challenge-seeking preference might not be as reliable as using an experimental measure, since self-reports are vulnerable to under-estimation or over-estimation biases. The current experiment aimed to examine whether agent likeability contributed to the social contagion of challenge-seeking behaviour.

It was hypothesised that,

1. participants would choose difficult word problems more frequently after watching the challenge-seeker confederate compared to their baseline challenge-seeking tendencies (i.e., replication of the previous results), and
2. this contagion effect would interact with the likability condition. Specifically, the social contagion of challenge-seeking behaviour would be greater in the liked confederate condition than in the disliked confederate condition.

Based on the hypotheses, it was predicted that the participants in the liked confederate condition would select difficult word problems more frequently after observing the challenge-seeker confederate, compared to the participants in the disliked confederate condition.

3.1. Method

3.1.1. Participants

90 participants took part in the experiment. The sample size was determined based on power calculation conducted in G*Power 3.1.9.7. using $\alpha = .05$, power = .80, and small to medium interaction effect size $f = 0.15$. Before data collection started, half of the participants were randomly assigned to the liked confederate condition and the other half were assigned to the disliked confederate condition. This was done by using the rand function in MATLAB.

Only heterosexual British females whose native tongue was English and who were studying for a bachelor's degree in psychology at the time were recruited for the experiment (please refer to Experimental Procedure for the reasoning). The participants' age ($M = 19.31$, $SD = 1.11$) did not significantly differ across the liked confederate ($M = 19.26$, $SD = 1.07$) and the disliked confederate ($M = 19.41$, $SD = 1.26$) conditions, $t(64.60) = -0.55$, $p = .584$, $d = 0.13$. Participants' mean math anxiety was 2.47 ($SD = 0.95$) out of 6, and it was not significantly different across participants in the liked confederate ($M = 2.46$, $SD = 0.85$) and the disliked confederate ($M = 2.34$, $SD = 0.91$) conditions, $t(67.75) = 0.54$, $p = .588$, $d = -0.13$. Participants were screened using the confederate plausibility criterion that was used for the first five behavioural experiments (please refer to the Method section in Chapter 2 for more details). This resulted in the exclusion of 13 participants ($M_{age} = 19.17$, $SD_{age} = 1.03$) who did not believe participants were real people. Additionally, 8 participants ($M_{age} = 19.25$, $SD_{age} = 0.71$) who incorrectly predicted that the confederate sought challenges in less than 50 % of the time were excluded from the statistical analysis (this differed slightly from the second exclusion criterion used in Experiment 1-5 as the current experiment only employed the challenge-seeker confederate).

The final sample consisted of 70 participants with a mean age of 19.33 (*SD* = 1.16, min = 18, max = 22) and a mean math anxiety of 2.40 (*SD* = 0.87) out of 6. Mean age and math anxiety scores of the included sample were not significantly different from the excluded participants' mean age (*M* = 19.21, *SD* = 0.92), $t(35.47) = 0.49$, $p = .630$, $d = -0.12$ or math anxiety scores (*M* = 2.70, *SD* = 1.17), $t(25.33) = 1.06$, $p = .299$, $d = 0.29$.

Anonymised data, analysis codes, supplementary analyses & materials (osf.io/qkrea) and preregistration of the experiment (osf.io/hsvtf) are available in Open Science Framework.

3.1.2. Experimental Procedure

This study was a single-session lab experiment, and it was conducted in the Harry Pitt building at the University of Reading, Reading, United Kingdom. Participants were seated in chairs placed in the doorway of two rooms, facing each other. The experimenter sat on a third chair placed in between the participants for the ease of giving simultaneous instructions to both participants.

Before the day of the experiment, participants were informed that the experiment would involve working on a couple of cognitive tasks with another participant. This instruction was vague, and the experimenter did not supply more information concerning who they would meet. Unbeknownst to the participant, this other participant was the confederate of the study and is referred to as such to avoid a possible confusion. The confederate was a performance arts student from the University of Reading, who responded to the recruitment post of the experiment. Participants recruited for the experiment matched the demographics of the confederate. The reason for matching the participant demographics to the confederate's was to increase participants' feelings of likeability for the confederate, based on the literature indicating that similar others were liked more (Amodio & Showers, 2005). Additionally, only heterosexual participants were recruited to control for the confounding effect of possible romantic feelings evoked towards the confederate in the liked-confederate condition.

On the day of the experiment, the participant was led to believe that she had arrived earlier than the confederate. The confederate arrived approximately 1 minute after the participant, and the way she greeted the participant depended on the likeability condition that the participant was assigned to. The participant and the confederate re-read the information sheet (which was previously sent to the participant via email during recruitment); and filled out the consent form upon their arrival.

The experimental procedure consisted of three phases. In Phase 1, the participant interacted with the confederate. In Phase 2, the participant played the Ultimatum Game. In Phase 3, the participant worked on the challenge-seeking task (Figure 19). Likeability manipulation was applied in Phases 1 and 2. The surveys designed to check the likeability manipulation were administered at the end of each phase (at 3 time points). The whole session lasted about 1 hour.

Phase 1: At the interaction phase, the participant met the confederate, and they chatted for 5 minutes whilst sitting on the chairs facing each other. During this time, the participant was led to believe that the experimenter was busy preparing the experiment setup. In the course of the interaction, the confederate's actions, facial expression and body posture were pre-defined based on the likeability condition that the participant was assigned to (explained in detail later). The contents of the conversation between the participants and the confederate were not set in stone but were limited to food preferences, schoolwork, and leisure-time activities. After 5 minutes, the experimenter intervened in the conversation between the participant and the confederate and initiated Phase 2.

Phase 2*:* The second phase started when the experimenter announced that the experiment was about to start. The participant and the confederate were asked to move their chairs to the experiment rooms they were assigned to. Then they were requested to fill out Survey T1 open on the web browser of the laptops assigned to each of them. Note that the doors of each room stayed open while they were filling out surveys and listening to the task instructions. This setup enabled the experimenter to switch between the different software used for tasks and surveys. Due to the angle of their seating area, the participant could not see the confederate even though the doors were open (Appendix D). The experimenter specifically instructed both parties not to talk to each other or leave their room for the duration of the experiment.

After the demographic information survey was completed, the experimenter asked the participant and the confederate to choose an avatar image for themselves. There were 8 cartoon animal images to choose from (explained further in the Method section of Experiment 2). During the avatar image selection, the participant was instructed that her and the confederate's laptops were connected, so they could observe each other's actions during the cognitive tasks introduced in the experiment. The participant and the confederate were instructed to pay attention to each other's avatar choices, as this information would be needed for the upcoming tasks. Unbeknownst to the participant, the avatar choice of the confederate was computer-selected and was always different from the participant's. After the avatar images were selected, the participant and the confederate were given instructions for the Ultimatum Game (Figure 19).

The doors were shut right before the participant and the confederate started the Ultimatum Game. The experimenter requested the participant to alert the experimenter by knocking on her door from inside when she was finished with the task. She was made aware that both herself and the confederate would finish at the same time and a knock from only one of them would be sufficient to alert the experimenter. When the participant knocked on her door, the experimenter opened hers and the confederate's door at the same time and asked them to fill out Survey T2. When they were finished, the experimenter initiated Phase 3.

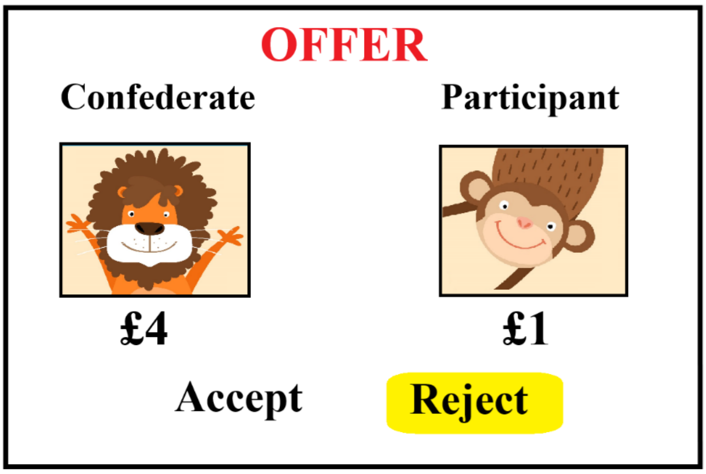
Phase 3: In Phase 3, the participant and the confederate worked on the challenge-seeking task (Figure 19). When the participant knocked on her door from the inside, to signal that she was finished with the task, the experimenter requested the participant and the confederate to complete the last survey (Survey T3). When the participant completed the survey, she was debriefed about the real aims of the experiment and compensated with either £10 or 1 school credit (SONA) based on her preference.

Figure 19

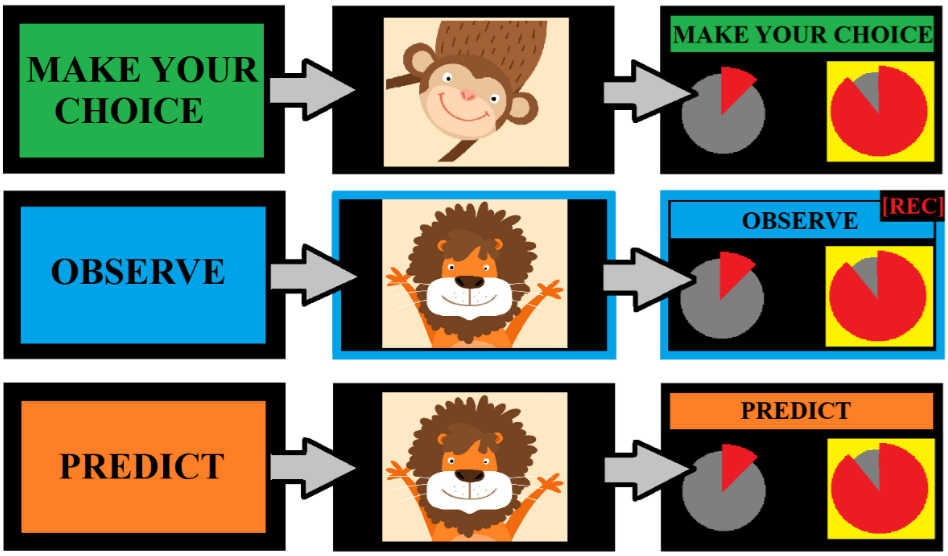
Experiment design as used in the Likeability Experiment

Phase 1: Mimicry manipulation

Phase 2: Ultimatum Game



Phase 3: Challenge-seeking task



Note. Phase 1: Participant met the confederate who either mimicked or did not mimic the behaviours of the participant (based on the likeability condition she was assigned to). Phase 2: Participant and the confederate played the Ultimatum Game in which confederate either behaved fairly (liked confederate condition) or unfairly (disliked confederate condition). Phase 3: Challenge-seeking task.

Ultimatum Game

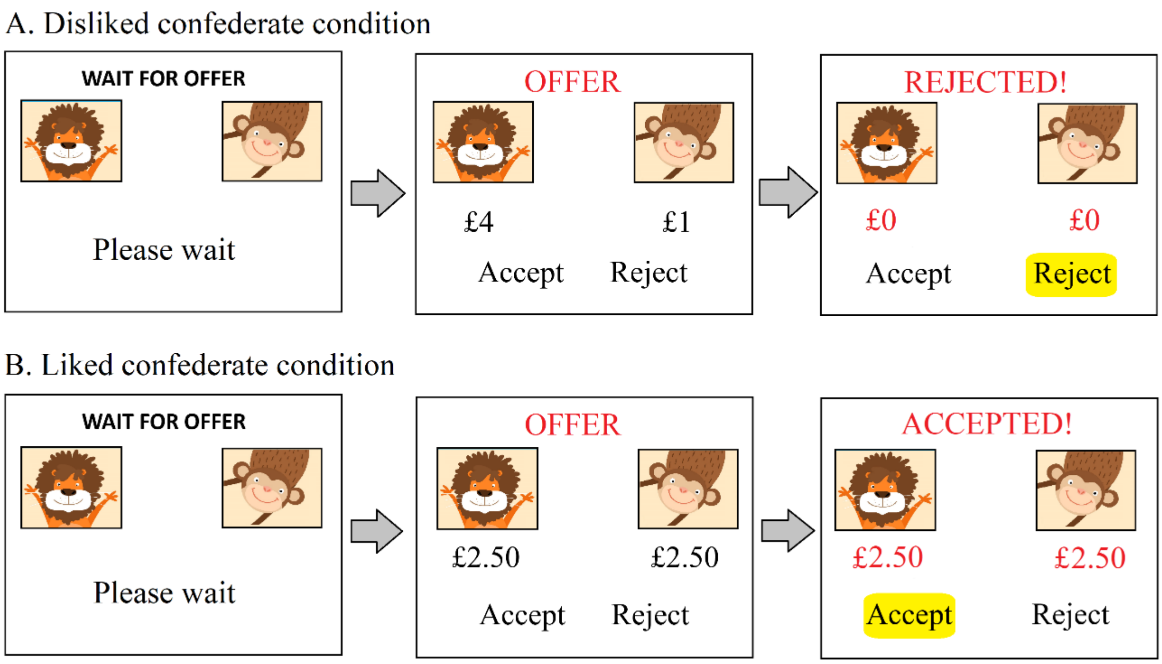
Ultimatum Game is a decision-making task widely used in neuroeconomics experiments (Sanfey et al., 2003; Oosterbeek et al., 2004). Briefly, the game is played between two participants: a proposer and a responder. These two individuals are given a sum of money. The proposer submits an offer on how to divide the two players. The responder either accepts or rejects the offer. If the responder accepts the offer, both players receive the amount as proposed. If the responder rejects the offer, no one gets any money. Previous literature showed that participants in the role of responder rejected unfair offers, even when it was not economically rational to do so. Responders regarded offers in which a larger portion was allocated to proposers and a smaller portion to themselves as unfair, leading them to typically decline such offers, even if it meant receiving nothing, as a way to punish the proposer (Sanfey et al., 2003). The Ultimatum Game was used as a likeability measure because previous literature showed that unfair proposers are generally disliked (Sanfey et al., 2003).

In the adapted version used for the current experiment (Figure 20), the proposer and the responder were given £5 to share. The confederate and the participant played a game of rock-paper-scissors for the proposer role. The rock-paper-scissor game was repeated twice, and the results were rigged. The result of the first game was always a tie, and the confederate always won the second game. Therefore, the confederate always had the proposer role. When the roles were selected, the experimenter closed the doors and the Ultimatum Game started.

The Ultimatum Game had 4 trials. If the participant was assigned to the liked confederate condition, the proposer offered her £2.50 from the sum of £5 in each trial. If the participant was assigned to the disliked confederate condition, the proposer offered her £0.50, £0.20, £0.25, £0.10, £0.05 or £0.75 from a total of £5. Unbeknownst to the participants, the proposer responses were computer-generated and randomly selected (for the disliked confederate condition).

Figure 20

Ultimatum Game



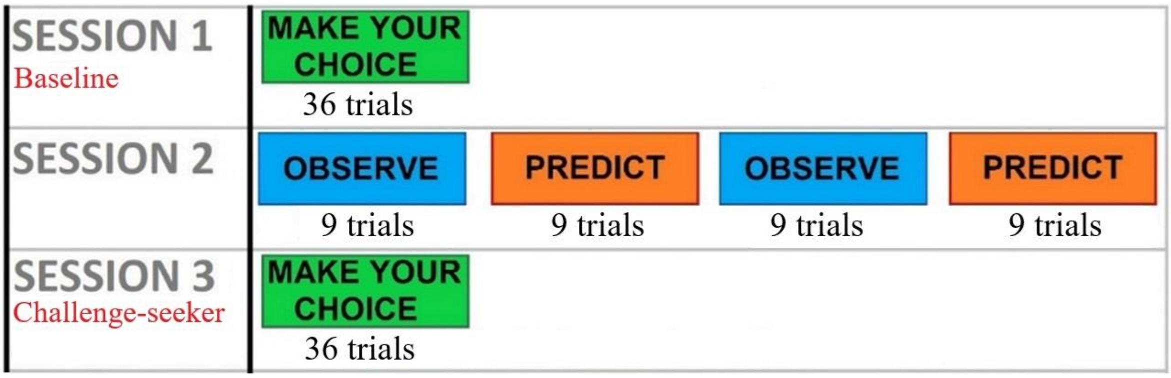
Note. Confederate was always the proposer, the player who suggested fair or unfair offers to divide the money. The participants were always the responders, the player who accepted or rejected the proposer's offers. (A) In the disliked confederate condition, proposer offered the participant £0.50, £0.20, £0.25, £0.10, £0.05 or £0.75 and kept the larger portion to herself. (B) In the liked confederate condition, proposer offered to divide the money equally.

Challenge-Seeking Task

The challenge-seeking task was modified from the version used in Experiment 5. In this version, the pie charts were presented on a black background. Since the first five experiments showed that observing a challenge-avoider did not significantly influence participants' challenge-seeking tendencies, the current version of the task did not employ a challenge-avoider confederate and instead focused on the effects of observing a challenge-seeker. Therefore, the revised version of the challenge-seeking task consisted of 3 sessions: (1) the participant's baseline challenge-seeking, (2) observation and prediction of challenge-seeker confederate's word problem choices and (3) the participant's challenge-seeking after observing the challenge-seeker confederate's word problem choices (Figure 21). Sessions 1 and 3 had 36 make-your-choice trials each and Session 2 had 18 observe and 18 predict trials, making a total of 108 trials. The task lasted about 15 minutes.

Figure 21

Session structure and number of trials in challenge-seeking task as used in the likeability experiment



Note. Shorter version of the challenge-seeking task which only measured the influence of the challenge-seeker confederate.

Likeability Manipulation

In order to manipulate the likeability of the confederate, the combination of three mechanisms which were shown to manipulate likeability was used: (1) similarity (2) mimicry and (3) fairness.

Similarity is a concept closely related to likeability. Similar others are liked more (Amodio & Showers, 2005) and befriended more easily (McPherson et al., 2001). The overlaps in attitudes, beliefs, and values between two individuals often lead to the development of pleasant feelings (Bryne & Nelson, 1965) and a desire to spend more time together in both parties (McPherson et al., 2001). Bryne and Nelson (1965) claimed that preferring similar others is reinforcing because it validates individuals' own beliefs and attitudes. Demonstrations of in-group bias, characterised as favouring those who belong to the same group as the individual, showed how similarity breeds liking (Billig & Tajfel, 1973).

Mimicry has also been associated with greater likeability (Chartrand & Bargh, 1999). The term mimicry refers to an (often) unintentional imitation of an interaction partner's body position (posture), speech patterns, gestures, facial expression, and/or behaviours (for a review, see Chartrand & Bargh, 1999). Individuals not only mimicked those whom they liked more (Bourgeois & Hess, 2008; Likowski et al., 2008; Stel et al., 2010) but also found those who mimicked them more likeable (Chartrand & Bargh, 1999; Lakin & Chartrand, 2003; Schilbach et al., 2008). For instance, mirroring an interaction partner's torso and arm posture facilitated feelings of rapport (LaFrance, 1979); matching the arm and leg position of a client led to greater empathy ratings for the councillor (Maurer & Tindall, 1983); copying the foot tapping and face touching behaviours of an individual increased likeability ratings for the mimicker (Chartrand & Bargh, 1999).

Fairness has been frequently used to manipulate likeability in social psychology experiments. For instance, Greenberg (1987) showed that participants rated the task and the experimenters more likeable when they were paid fairly (based on performance) compared to when treated unfairly (based on luck). Furthermore, studies employing experimental economics games (e.g., Ultimatum Game, Prisoner Dilemma) demonstrated that fair players were liked more while unfair ones were disliked to the extent that mistreated participants sacrificed their reward to punish the unfair player (Sanfey et al., 2003) and derived satisfaction from their pain (Singer et al., 2006).

The reason for using the combination of three different methods was to ensure the strong effects of manipulation. Due to potential individual differences in sensitivity to similarity, mimicry or fairness, participants might not have been influenced in the direction desired. Therefore, combining three manipulation methods that were associated with likeability ratings was believed to be more effective.

The following criteria were used to create liked and disliked confederate conditions.

Liked Confederate Condition

1. Similarity manipulation: In Phase 1, the experimenter asked questions to the participant and then to the confederate. The confederate's answers to these questions were similar to those of the participant. For instance, if the participant reported studying bachelor's degree in psychology and accommodating in dormitories, so did the confederate. Additionally, the confederate showed agreement with the participant's opinions during their talk. For instance, if the participant said she stayed

up late studying for an exam, the confederate also mentioned that she studied hard for the same exam.

2. Mimicry manipulation: The confederate mimicked the facial expressions, body posture, and speech volume of the participant. If the participant avoided eye contact, so did the confederate. If the participant sat relaxed in the chair, so did the confederate.
3. Fairness manipulation: In the Ultimatum Game, the confederate divided the money equally.

Disliked Confederate Condition

1. Similarity manipulation: In Phase 1, the confederate mentioned she had been studying for a bachelor's degree in maths and had been accommodating in private student housing. The confederate also disagreed with the participant's opinions, values, and beliefs during their chat. For instance, if the participant said her favourite meal was hamburger, the confederate mentioned she was a vegan.
2. Mimicry manipulation: The confederate did not mimic the facial expressions, body posture, or speech volume of the participant. If the participant sat relaxed in the chair, the confederate sat up straight.
3. Fairness manipulation: In the Ultimatum Game, the confederate offered the participant very little money (e.g., £0.50), while taking the larger portion for herself (e.g., £4.50).

3.1.3. Surveys

The survey data were collected using REDCap electronic data capture tools (Harris et al., 2009; 2019) hosted at the University of Reading. Surveys were administered at three time points: (T1) after meeting the confederate, (T2) after the Ultimatum Game and (T3) after the challenge-seeking task. Each survey included a likeability and a competitiveness rating. The likeability rating asked the participant to rate how likeable she thought the other participant she just met was. The scale provided for likeability rating ranged from 1 (not at all) to 7 (very likeable). The competitiveness rating was added as an exploratory measure and contained a single item asking the participant to rate how competitive she felt towards the participant she just met. The scale provided ranged from 1 (not at all) to 5 (very competitive). There was also a single item asking the participant to rate how compatible she and the other participant she just met would be if they were to work together. The scale provided for the compatibility item ranged from 1 (not at all) to 7 (very compatible). Importantly, the compatibility ratings were not analysed as it was not related to the hypothesis. The compatibility rating was only added upon a colleague's concern about possible misinterpretation of the likeability measure. The aim was to direct participants' attention away from the likability concept in romantic relationships. The compatibility item was only added to Surveys T1 and T2.

In addition to the likeability, competitiveness and compatibility measures, each survey employed extra questions. In Survey T1, information on participant demographics (age, gender and ethnicity), participants' stress levels, hours of sleep and self-reports of math anxiety was collected. In Survey T2, attention check questions about the Ultimatum Game (e.g., Which avatar image did the other participant choose?) were used. In Survey T3, task concentration, perceived intelligence of the confederate, and plausibility of the experiment elements (plausibility of the confederate and the problem-solving session) were rated. Survey T3 additionally measured participants' goal orientations using a multiple-choice item adapted from Mastery-avoid & approach and performance-avoid & approach items from Achievement Goal Questionnaire–Revised (AGQ-R), (Elliot & Murayama, 2008) and Interest/Enjoyment subscale of Intrinsic Motivation Inventory (IMI) (Ryan & Deci, 2000) (Appendix E).

3.2. Data Analysis

Participants' word problem choices before and after observing the challenge-seeker confederate were compared. The dependent variable was the challenge-seeking rate, which was operationalised as the proportion of make-your-choice trials where the participant chose to solve the more difficult word problem.

The data analysis was conducted using RStudio 2022.7.1.554 (RStudio Team, 2022) and IDE for R version 4.1.3 (R Core Team, 2022). Mixed ANOVA was conducted using the 'anova_test' function from the 'rstatix' library (Kassambara, 2022). Post-hoc t-tests were conducted using the 'pairwise_t_test' function in the 'stats' library (R Core Team, 2022) and corrected for multiple comparisons using the Bonferroni-Holm method. Exploratory logistic GLM analysis was conducted using the 'glmer' function from the 'lme4' library (Bates et al., 2015). Figures were created using the 'ggplot2' (R Core Team, 2022) library as well as the 'Open visualizations in R and Python tutorial' (Langen, 2020).

3.3. Results

3.3.1. Experimental Manipulation Check

Likeability: Mean likeability ratings in Survey T1 (Phase 1, before the Ultimatum Game, but after the interaction), Survey T2 (Phase 2, after the Ultimatum Game), and Survey T3 (after the challenge-seeking task) were compared with a 2 (confederate likeability: liked confederate, disliked confederate) by 3 (time: T1, T2, T3) mixed ANOVA. The main effect of confederate likeability condition was significant, $F(1, 68) = 213.26$, $p < .001$, $\eta_G^2 = .72$. Overall, participants in the liked confederate condition rated the confederate as more likeable ($M = 6.22$, $SD = 0.76$) than the ones in the disliked confederate condition ($M = 3.08$, $SD = 1.32$), indicating the successful manipulation of likeability. The main effect of time was also statistically significant, $F(2, 136) = 18.10$, $p < .001$, $\eta_G^2 = .05$. Likeability ratings for the confederate fluctuated through the time course of the experiment, Survey T1 ($M = 4.96$, $SD = 1.50$), Survey T2 ($M = 4.44$, $SD = 2.19$) and Survey T3 ($M = 4.54$, $SD = 1.95$).

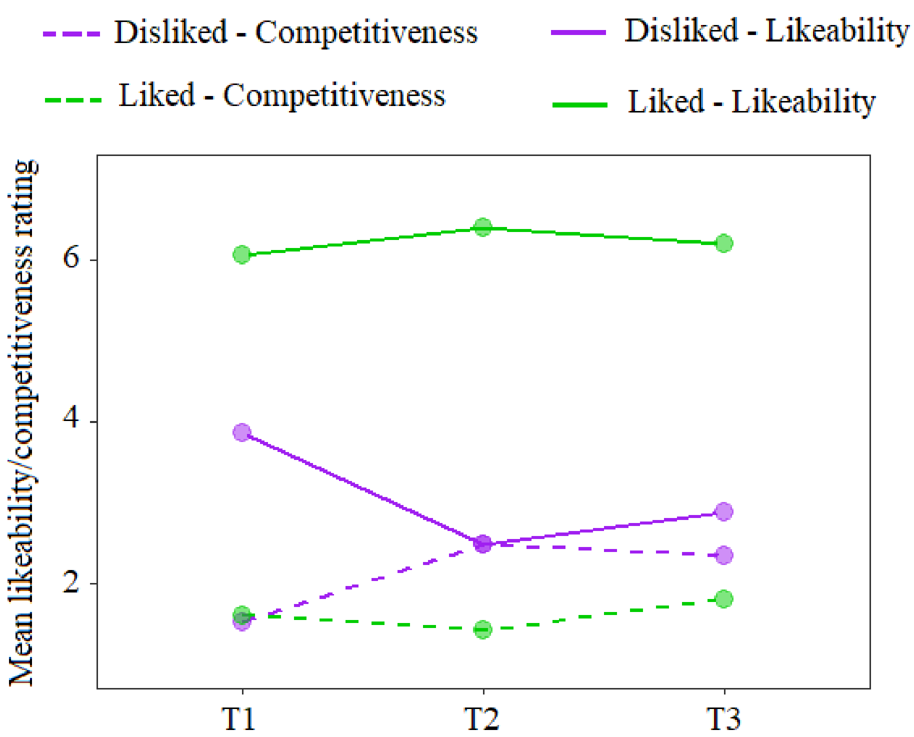
Importantly, the interaction effect of confederate likeability and time was significant as well, $F(2, 136) = 46.06$, $p < .001$, $\eta_G^2 = .12$. At each time point, those in the disliked confederate condition rated the confederate significantly less likeable than those in the liked confederate condition (Table 3). However, the effect size was greater in Survey T2. Participants in the disliked confederate condition rated the confederate significantly less likeable at Survey T2 ($M = 2.49$ $SD = 1.15$) compared to the participants in the liked confederate condition ($M = 6.4$, $SD = 0.74$). It means that, although the likeability manipulation was successful overall, the effect was reduced after the challenge-seeking task.

Competitiveness: Participants' competitiveness ratings at the start, midway and at the end of the experiment were compared with a 2 (confederate likeability: liked confederate, disliked confederate) by 3 (time: Survey T1, Survey T2, Survey T3) mixed ANOVA. Results showed a significant main effect of the confederate likeability condition, $F(1, 68) = 7.05$, $p = .01$, $\eta_G^2 = .07$. Participants assigned to the disliked confederate condition rated their feelings towards the confederate as significantly more competitive ($M = 2.11$, $SD = 1.11$) than those assigned to the liked confederate condition ($M = 1.61$, $SD = 0.87$). This means that the likeability manipulation also changed the competitive feelings of participants. The main effect of time was also statistically significant, $F(1.77, 120.06) = 12.18$, $p < .001$, $\eta_G^2 = .05$. In general, competitiveness ratings increased as the experiment progressed, Survey T1: $M = 1.56$, $SD = 0.81$; Survey T2: $M = 1.96$, $SD = 1.07$; and Survey T3: $M = 2.07$, $SD = 1.12$.

Importantly, the interaction effect of confederate likeability and time conditions was statistically significant, $F(1.77, 120.06) = 13.68$, $p < .001$, $\eta_G^2 = .06$. At the beginning of the experiment, competitiveness ratings given by those in different confederate likeability conditions were not significantly different (Figure 22). However, right after the likeability manipulation (Survey T2), the competitiveness ratings of participants in the disliked confederate condition were significantly greater compared to those in the liked confederate condition (Table 3). Similar competitiveness ratings of participants from both likeability conditions in Survey T3 show that the manipulation was not long-lasting.

Figure 22

Likeability and competitiveness ratings of participants in liked and disliked conditions, collected at three time points



Note. (T1) after meeting the confederate, (T2) after the Ultimatum Game and (T3) after the Challenge-seeking task. Likeability ratings ranged from 1 (not at all) to 7 (very likeable) and competitiveness ratings ranged from 1 (not at all) to 5 (very competitive).

Table 3

Means, standard deviations of participants' likeability and competitiveness ratings at each phase together with the t statistics, degrees of freedom and p values.

Likeability						
	Liked *M* (*SD*)	Disliked *M* (*SD*)	*t*	*df*	*p*	*d*
T1	6.06 (0.76)	3.86 (1.22)	9.06	57.3	<.001	2.17
T2	6.40 (0.74)	2.49 (1.15)	17.00	57.9	<.001	4.06
T3	6.20 (0.76)	2.89 (1.23)	13.6	56.6	<.001	3.24
Competitiveness						
T1	1.60 (0.91)	1.51 (0.70)	0.44	63.7	1	0.11
T2	1.43 (0.70)	2.49 (1.12)	4.74	56.9	<.001	1.13
T3	1.80 (0.96)	2.34 (1.21)	2.07	64.7	.126	0.50

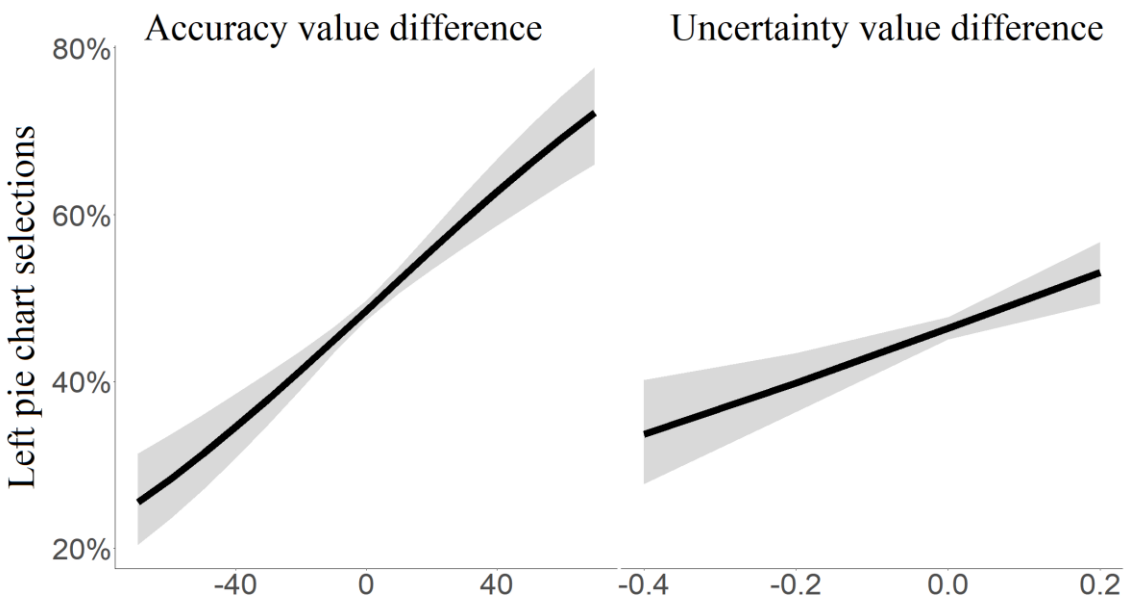
Note. Likeability scale ranged from 1 (not at all) to 7 (very likeable) and competitiveness scale ranged from 1 (not at all) to 5 (very competitive). All *p* values were corrected for multiple comparisons using Bonferroni-Holm method.

3.3.2. Participant's Challenge-Seeking at Baseline

In accordance with the results of Experiments 1-5, participants' choices were guided by the difficulty of the word problems. A challenge avoidant attitude at baseline was replicated with the challenge-seeking rate of .13 (*SD* = 0.19). As the difference between the accuracy levels of the pie charts increased, participants selected harder word problems less frequently, $\beta = 0.01$, $SE = 0.002$, 95% CI [0.01, 0.02], $p < .001$ (Figure 23).

Figure 23

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

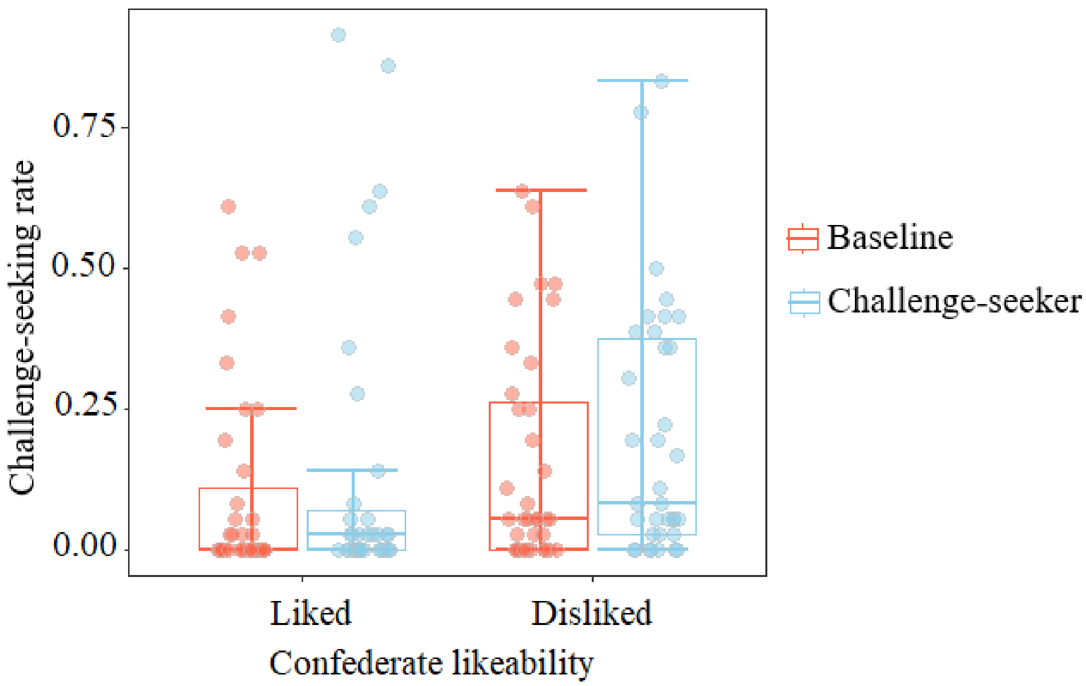
3.3.3. The Social Contagion of Challenge-Seeking

A 2 (observation condition: baseline, challenge-seeker; within subjects) by 2 (confederate likeability: liked confederate, disliked confederate; between subjects) mixed ANOVA was conducted. Main effect of observation condition, main effect of confederate likeability condition or their interaction effect were not significant, $F(1, 68) = 3.62$, $p = .060$, $\eta_G^2 = .01$; $F(1, 68) = 1.71$, $p = .196$, $\eta_G^2 = .02$; $F(1, 68) = 0.05$, $p = .833$, $\eta_G^2 = .0001$, respectively. Although the social contagion of challenge-seeking behaviour could not be replicated in terms of statistical significance in this experiment, a trend in the direction of the results obtained from Experiments 1-5 existed ($p = .060$). Regardless of the confederate likeability condition, challenge-seeking behaviour was greater after observing the challenge-seeker confederate (*M* =0.17, *SD* = 0.24), compared to the baseline condition (*M* = 0.13, *SD* = 0.19) (Figure 24).

Participants who were assigned to the disliked confederate condition had greater baseline challenge-seeking rates (*M* = 0.16, *SD* = 0.19), compared to those in the liked confederate condition (*M* = 0.10, *SD* = 0.18), although the difference was not significant, $p = .202$.

Figure 24

Challenge-seeking rates of participants who were assigned to liked confederate and disliked confederate conditions



Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with red points for baseline and blue points for challenge-seeking conditions. Box plots show median challenge-seeking rates and lower & upper quartile values in each observation condition for each confederate likeability group.

3.3.4. Uncertainty Resolution

Participants were more likely to choose the word problem with higher uncertainty value (word problem with the accuracy level closer to 50%). This tendency got stronger with the increasing difference between the entropy values of the word problems, β =1.34, *SE* = 0.35, 95% *CI* [0.65, 2.02], $p < .001$ (Figure 23). Importantly, a 2 (confederate likeability condition: disliked confederate, liked confederate) by 2 (observation condition: baseline, challenge-seeker) did not reveal a significant main effect of confederate likeability condition, $F(1, 68) = 0.02$, $p = .894$, $\eta_G^2 = 0.00$; main effect of observation condition, $F(1, 68) = 1.37$, $p = .247$, $\eta_G^2 = 0.01$, or an interaction effect, $F(1, 68) = 0.01$, $p = .927$, $\eta_G^2 = 0.00$, on uncertainty resolution related behaviour. Therefore, the observed social contagion effects are not likely related to uncertainty resolution.

3.4. Conclusions

Participants had an overall tendency to stay away from challenging word problems at the baseline, a finding consistent with the results of Experiments 1-5. Surprisingly, the social contagion of challenge-seeking was not replicated. Although participants selected harder word problems more frequently after observing the choices of the challenge-seeker confederate, this increase was not significantly greater than their baseline choices. One likely possibility for not replicating the social contagion effect may be the lack of statistical power. In fact, although not statistically significant, the direction and the size of the effects were similar to the previous experiments. Another possibility may be that the results of Experiments 1-5 cannot be generalised to face-to-face interactions. However, if this was the case, the pattern of behaviours would not be in the expected direction. Another, more convincing, possibility might be that the participants were too tired to seek challenges. Before participants started the challenge-seeking task, they went through a series of tasks and surveys conducted to induce the likeability manipulation. This manipulation procedure lasted about 30 minutes. It is possible that switching between various tasks (rock-paper-scissors, Ultimatum Game and challenge-seeking task) exhausted the cognitive resources of the participant. As a consequence, they were less motivated to take on challenges. Recall that a similar result was obtained in Experiment 4. Frequent task switching between the perceived difficulty and self-confidence ratings and the challenge-seeking task reduced participants’ overall challenge-seeking rates.

Critically, the current experiment could not find evidence pointing to an association between confederate likeability and susceptibility to the social contagion of challenge-seeking. Possibly the weakened likeability manipulation had a role in not observing the predicted link between the social contagion and confederate likeability. When likeability ratings were compared across three time points before and after the challenge-seeking task (T2 and T3), a notable decrease in likeability manipulation was observed at the end of the challenge-seeking task (T3). Perhaps attending to the challenge-seeking task reduced the strength of likeability manipulation. However, this is only a speculation, as the strength of confederate likeability was not measured in the middle of the challenge-seeking task.

Chapter 4: Neural Correlates of Challenge-Seeking Contagion

The aim of the fMRI experiment was to investigate the neural underpinnings of the social contagion of challenge-seeking behaviour in order to understand the underlying mechanisms for the observed effects. Considering the intrinsically rewarding properties of challenge-seeking behaviours and the decision-conflict involved in opting to seek challenges rather than easier alternatives, the reward hub of the brain, the striatum, and the conflict monitoring region of the brain, ACC, were expected to be associated with challenge-seeking behaviours and their contagion.

According to Bandura (1977), observing others receiving positive or negative reinforcement, *vicarious reward*, is an important determinant of motivated behaviour. The observer is inclined to infer the mental state of the performer and form expectations about their experience (Wild et al., 1992). For example, witnessing someone deeply engrossed in their book despite the noisy ambiance of a coffee shop would spark positive anticipation about the book's content, prompting the observer to consider reading the same book. Similarly, in instances of challenge-seeking behaviours, observing the challenge-seeker confederate might have led to the experience of a similar vicarious reward, encouraging participants to seek challenges. Therefore, vicarious reward might be the underlying mechanism for the social contagion of challenge-seeking behaviours. Based on the previous reports of enhanced striatal activations in intrinsic reward processing (Hassani et al., 2001; Knutson et al., 2001; Tricomi et al., 2006; Delgado, 2007; Mizuno et al., 2008; Kang et al., 2009; Schmidt et al., 2012; Murayama et al., 2015), changes in the striatum may be associated with the social contagion of challenge-seeking behaviours.

Another brain region that might be associated with the social contagion of challenge-seeking is the anterior cingulate cortex. This area has been linked to cognitive resource recruitment (Kong et al., 2005; Vassena et al., 2014) and decision conflict (Sanfey et al., 2003; Ernst et al., 2004). Inferring the mental state of the challenge-seeker confederate may not only inform participants about the quality of engagement (e.g., enjoyment) but also signals the participant to recruit cognitive resources required to solve difficult problems. Furthermore, the decision conflict that the confederate experiences while choosing between difficult and easy problems (i.e., the confederate chooses a difficult problem despite easier alternatives) might also be transferred through vicarious experience.

Therefore, it was hypothesized that the social contagion of challenge-seeking behaviour is associated with striatal activations representing the intrinsic value of seeking challenges and with the anterior cingulate cortex activations associated with difficult task preparation and decision conflict. Based on the hypotheses, it was predicted that,

1. in general, hard problem choices compared to easier ones would be accompanied by enhanced ACC activation,
2. challenge-seeker condition would be associated with enhanced activity in the striatum and ACC, compared to baseline and challenge-avoider conditions.

In addition to the predictions regarding the neural activity, it was predicted that observing the challenge-seeker confederate would increase, and observing the challenge-avoider confederate would decrease participants' challenge-seeking rates.

4.1. Method

4.1.1. Participants

43 participants (36 females) took part in the experiment. They had a mean age of 26.09 (*SD* = 5.92, age range = 20 to 41) and a mean math anxiety score of 2.28 (*SD* = 0.96) out of 6. One participant withdrew from the study mid-scanning and was therefore excluded from statistical analysis. Five participants showed excessive head motion inside the scanner and went above the pre-specified threshold of 1.5 mm/degree maximum frame-wise displacement value (Appendix F) suggested by Di and Biswal (2023). 13 participants' data showed a lack of variance (e.g., selecting the same option across a scanning session) and therefore could not be added to the GLM model.

Exclusion criteria used in behavioural (online) experiments were applied to the fMRI experiment as well. From the remaining sample, one participant was excluded from the statistical analysis for providing inaccurate predictions of the confederates' challenge-seeking tendencies. In order to maintain statistical power, instead of eliminating those who reported disbelief in the confederates' genuineness, samples with and without the exclusion of these participants were compared. Pre-processing and statistical analyses were conducted on the remaining 24 participants (18 females). The sample had an age range of 20 to 41 and a mean age of 26.67 (*SD* = 5.55). The mean math anxiety score was 1.92 (*SD* = 0.83) out of 6.

Excluded participants' age (*M* = 25.37, *SD* = 6.43) or gender (18 females) characteristics were not significantly different from the included sample (age: *t*(35.77) = 0.70, *p* = .490, *d* = 0.22, gender: x^2(1, *N* = 43) = 1.76, *p* = .185). However, excluded participants' math anxiety scores (*M* = 2.74, *SD* = 0.93) were significantly greater than those of included participants, *t*(36.41) = 3.00, *p* = .005, *d* = 0.93.

Sensitivity analysis (performed using G*Power 3.1.9.7, with a significance level (α) of .05, and a power of .80) indicated a minimal statistically detectable effect size of 0.44 (*dz*).

Anonymised data, analysis codes, and supplementary analyses & materials (osf.io/qkrea) are available in Open Science Framework.

4.1.2. Experimental Procedure

Participants were recruited via mailing lists and the SONA participation pool system at the University of Reading. After they confirmed that they met the standard health and safety screening conditions of being inside the scanner, they received a copy of the information sheet of the study via email. On the day of the scanning, they were requested to fill out the fMRI health and safety screening form, informed consent form and demographic information survey before entering the MRI room.

Before being accompanied to the scanner, they read the instructions for the challenge-seeking task and practised it for the duration of 3 trials. During the instructions phase, they were requested permission to replay their choices in the task anonymously to future participants of the study. Those who accepted chose an avatar image across various cartoon animal images and created a nickname for themselves. As was the case in Experiments 1- 5, this procedure was used to maintain the plausibility that two confederates demonstrated throughout the experiment were recordings from previous participants of the study. After choosing a nickname and an avatar image, they saw the avatar image and the nickname chosen by the two confederates. The avatar image selected for the confederate was always different from what participants chose.

After they completed the challenge-seeking task, they stayed inside the scanner for another 5 minutes for the acquisition of anatomical images. Participants were thanked and given a copy of the debrief form which explained the real aims of the study. They were compensated either with 1 SONA course credit or £15 per hour of their participation. This study was approved by the University Research Ethics Committee at the University of Reading (UREC; Ethics Approval number: UREC 21/08).

Challenge-Seeking Task: The task was similar to the one used in Experiment 4 (detailed in the second chapter) except for the following features.

- The stimuli were presented on a black screen.
- Participants were asked to fixate on a white cross symbol at the centre of the screen during inter-trial intervals (as used in Experiments 1-5 and Likeability Experiment; *M* = 3 secs, min = 2 secs, max = 6 secs).
- Right-handed participants pressed the button placed under their index finger to select the pie chart on the left, and the button under their middle finger to select the pie chart on the right side of the screen. Left-handed participants did the opposite (middle finger for the left pie chart and index finger for the right pie chart).

4.2. Data Analysis of Behavioural Data

Behavioural data was analysed using RStudio 2022.7.1.554 (RStudio Team, 2022) and IDE for R version 4.1.3 (R Core Team, 2022). Mixed ANOVA was conducted using the 'anova_test' function from the 'rstatix' library (Kassambara, 2022). Post-hoc t-tests were conducted using the 'pairwise_t_test' function in the 'stats' library (R Core Team, 2022) and corrected for multiple comparisons using the Bonferroni-Holm method. Exploratory logistic GLM analysis was conducted using the 'glmer' function from the 'lme4' library (Bates et al., 2015).

4.3. fMRI Data Acquisition

Data collection was conducted at the Centre for Integrative Neuroscience and Neurodynamics (CINN), University of Reading using a 3.0 Tesla Siemens MAGNETOM scanner with a 32-channel head coil.

Whole-brain functional images were acquired using a T2*-weighted echo planar imaging (EPI) sequence (echo time (TE) = 30 ms; repetition time (TR) = 2000 ms; flip angle = 90˚). 37 axial slices aligned to anterior–posterior commissure (AC-PC) plane and interleaved from bottom to top (in-plane resolution of 3 x 3 x 3 mm, interslice gap: 3.75mm, field of view (FoV) = 192 x 192 mm^2; in-plane matrix: 64 x 64) were collected per volume.

A high-resolution T1-weighted three-dimensional anatomical image was acquired using an MPRAGE-gradient sequence with 192 slices (in-plane resolution of 0.9 x 0.9 x 0.9 mm; TE = 2.29 ms; TR = 2300 ms; inversion time (TI) = 900 ms; FoV = 240 x 240 mm^2; flip angle = 8°).

4.4. Pre-processing of the fMRI Data

4.4.1. Visual Inspection Phase in fMRI Data Quality Check

Raw fMRI data (both anatomical and functional data) were visually inspected for artifacts. Noisy volumes spotted during the visual inspection were marked and compared to the pre-processed versions (using SPM's pre-processing pipeline, as explained in detail below) to see if artifacts spotted in the visual inspections were removed properly at the pre-processing stage.

T1-weighted data were visually inspected for artifacts occurring due to wrap-around, subject motion or rotation, field inhomogeneity, RF-zipper, RG-spike, reconstruction, low SNR, non-linear distortion, and dental operations.

Visual inspection of anatomical data showed motion-induced spike artifacts in five participants (subjects 29, 37, 38, 39, and 40); low signal intensity in one participant (subject 27) and blurry image due to respiratory motion in one participant (subject 19). Additionally, one subject showed artifacts outside of the skull.

Visual inspection of functional data showed sudden head movements at multiple time points in twelve participants (participant 06, 19, 20, 21, 28, 29, 33, 34, 35, 37, 38, 40) and signal loss in 6 participants (participant 04, 27, 29, 34, 36 and 39).

Borders of the occipital lobe (participant 03) and cerebellar tonsils (participants 02 and 08) could not be captured due to these participants' positioning in the scanner. None of the participants showed structural anomalies, such as enlarged ventricles or cysts.

4.4.2. fMRI Data Quality Check Using the pyfMRIqc Software

pyfMRIqc software (Lindner, 2021) was run on raw functional data, except for participant 03 because of an error in its slice dimensions (60 x 64). Masks were created with the minimum mean voxel intensity threshold of 200, and SNR was calculated using 5% of the voxels with the lowest mean time course values. Mean voxel SNR ranged from 761 to 3574.

Global vertical patterns in the mean voxel time course of bins and peaks in QC plots showing mean scaled squared difference (SSD) across all volumes indicated the existence of local and/or global changes in signal variance for ten participants. More specifically, 4 participants showed global signal loss at multiple volumes, confirmed by negative peaks in QC plots of normalised amplitudes at the first 100 volumes (participant 4), between volumes 100-150 (participant 28), and at volumes after 350 (participants 34 and 39). Additionally, 6 participants showed large head motion accompanied by multiple smaller head motions (participants 14, 21, 27, 29, 35 and 38). According to the QC plot showing slice-wise mean SSD, other slices were also affected by the head motion these participants had. Participants were not discarded at this stage. Although this was a sign that the data from these six participants may be noisy, participants were excluded based on the translation and rotation parameters obtained during the spatial realignment phase of data pre-processing (see below).

4.4.3. Pre-processing Steps

Image pre-processing was conducted using Statistical Parametric Mapping 12 software (SPM12) by following the standard pipeline reported in the SPM12 manual (Ashburner et al., 2014). Each participant’s anatomical image was defaced for anonymisation; original images were removed. The first 4 volumes of the functional data were discarded to avoid MRI saturation effects. Slice timings were corrected by aligning all slices to the time point of the first slice. Functional images were spatially realigned to the first volume to calculate the amount of translation (in mm) and rotation (in degrees) applied to each volume. At this stage, volumes with maximum translation and rotation parameters above half the voxel size (>1.5 mm frame displacement) were identified; and used to exclude participants with excessive head motion (Appendix F). As a result, 5 participants (participants 28, 29, 34, 35, 37) were discarded from the statistical analysis. Functional data were unwarped using a field map to account for magnetic field inhomogeneities. Anatomical and functional images were co-registered. The structural image was segmented with inverse and forward models. Functional and co-registered structural data were normalised to the Montreal Neurological Institute (MNI) standard space. Finally, functional images were spatially smoothed using an 8-mm Gaussian kernel to account for inter-subject variability.

4.5. Data Analysis of the fMRI Data

The main focus of the analysis was identifying the neural representation of participants' challenge-seeking behaviours across different observation conditions. Therefore, separate regressors were created for easy and hard choices for each observation condition. Individual contrasts were generated to investigate (1) the main effect of selected word problem difficulty (e.g., hard choice > easy choice), (2) the main effect of observation condition (e.g., baseline > challenge-seeker) and (3) the interaction effects of selected word problem difficulty and observation condition (e.g., baseline hard-easy choice > challenge-seeker hard-easy choice). Moreover, for each contrast of the main and interaction effects, the intensity value of each voxel (β) included in the ROIs was averaged for each participant, and the vector consisting of the mean voxel intensity value for each participant was compared against the Null Hypothesis using a one-sample t-test. This was conducted separately for striatum and ACC ROIs. Additionally, individual contrasts focused on the simple main effects of word problem difficulty and observation conditions were created to examine the effects of selected word problem difficulty between observation conditions (e.g., baseline hard choice > challenge-seeker hard choice) and within observation conditions (e.g., baseline hard choice > baseline easy choice). Based on the hypotheses defined, the ROI analyses were considered a priori. However, as an exploratory analysis, the same set of analyses were conducted at the whole-brain level as well.

BOLD signals were modelled with two GLMs created using Statistical Parametric Mapping 12 software (SPM12). In GLM-I, regressors of interest were challenge-seeking behaviours (at the time of decision) in make-your-choice trials for the three observation conditions (baseline, challenge-seeker and challenge-avoider conditions) for each subject. Challenge-seeking behaviour (selection of the low-accuracy pie chart) and challenge-avoiding behaviour (selection of the high-accuracy pie chart) were separately defined. GLM-I had a total of 6 regressors of interest.

GLM-II was defined in order to account for the possible contribution of each trial's challenge magnitude on the model. The challenge magnitudes of pie charts were calculated by scaling down their accuracy value to the range of 0 to 1 and subtracting the outcome from 1 (Figure 1). Note that the accuracy values and challenge magnitudes of pie charts were negatively correlated. A large accuracy value indicated a large population of participants correctly answering the word problem that the pie chart represented.

Therefore, pie charts with large accuracy values represented less challenging word problems. For instance, if a pie chart's accuracy was 75%, then its challenge magnitude was 0.25. The higher the challenge magnitude value was, the higher the tendency to seek challenges. GLM-II contained two parametric modulators created using the challenge magnitudes of pie charts: (1) the *choice-dependent challenge magnitude of the trial* and (2) the *choice-independent challenge magnitude of the trial*. The choice-dependent challenge magnitude of the trial was calculated by subtracting the challenge magnitude of the not-chosen pie chart from the chosen pie chart. The choice-independent challenge magnitude of the trial was calculated by taking the mean of both pie charts' challenge magnitudes (Figure 25). These two parametric modulators were applied to the regressors of interest defined in GLM-I. Therefore, GLM-II had a total of 18 regressors of interest. Note that none of the parametric modulators were orthogonalised.

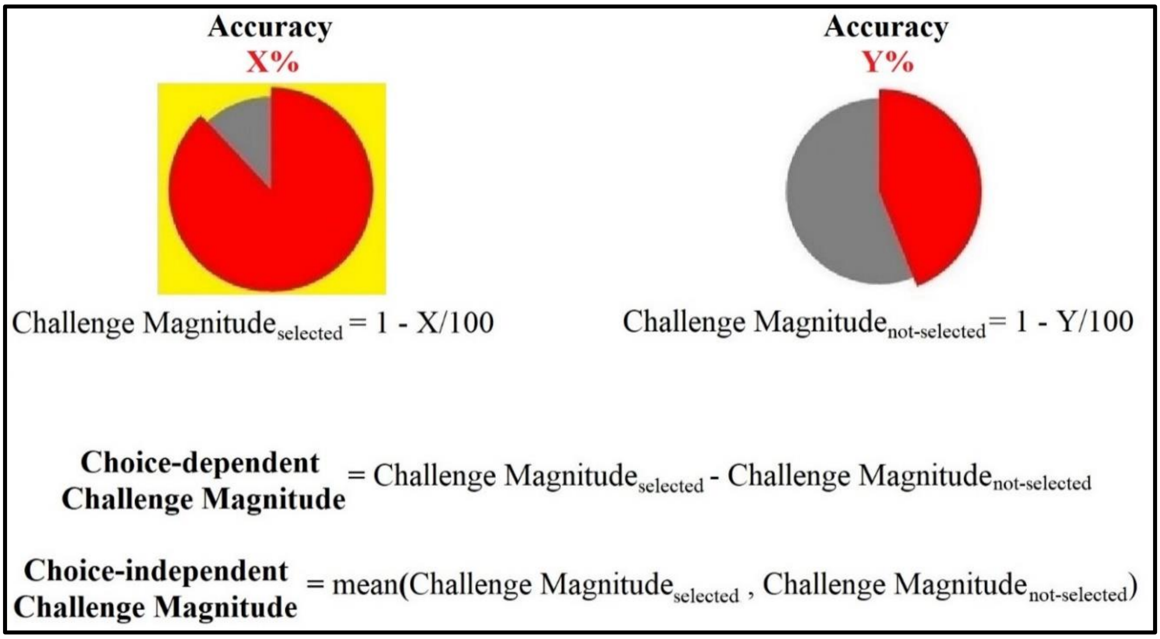
The decision phase (when participants responded) and the confirmation phase (when participants' choice was highlighted in yellow) of easy and hard choices in observe and predict trials were added to both GLMs as regressors of no interest, as well as participants' hand movements (left pie chart selection = index finger movement; right pie chart selection = middle finger movement), cue images used for instructions, avatar images (only in observe and predict trials), miss trials, head motion parameters calculated at the pre-processing phase, and average fMRI signal within session (intercept).

Contrast images indicating effects of interests were calculated for each participant for each observation condition and each selected word problem difficulty and they were entered into the second-level analysis in which participants' contrast of interests were compared using *t*-tests. For the ROI analysis mean BOLD signal in striatum and ACC during contrasts of interest were compared using *t*-tests.

The results were thresholded at the voxel level using the threshold of $p < .001$ (uncorrected) with a cluster extent of $k \geq 5$ voxels for the ROI analysis, and of $k \geq 50$ voxels for the whole-brain analysis. However, only the clusters that survived the family-wise error correction (FWE) threshold of $p < .05$ for whole brain analysis, and FWE of $p < .05/2$ for the ROI analysis (for conducting the same set of *t*-tests for 2 ROIs) were reported. Activated brain regions and cluster sizes in the whole brain analysis were acquired using the Atlas Reader package (Notter et al., 2019) in Python 3.11.2 (Van Rossum & Drake, 2009). The *t*-maps from ROI analysis and whole-brain analyses were generated using plotting.view_img function in nilearn package (Abraham et al., 2014) in Jupyter Notebook (Kluyver et al., 2016) and Python 3.11.2 (Van Rossum & Drake, 2009), and represented on the "avg152T1.nii" template anatomical image from SPM12 library. All coordinates reported are in the Montreal Neurological Institute (MNI) space.

Figure 25

Calculation of parametric modulators used in GLM II.



Note. Chosen pie chart is the one highlighted in yellow.

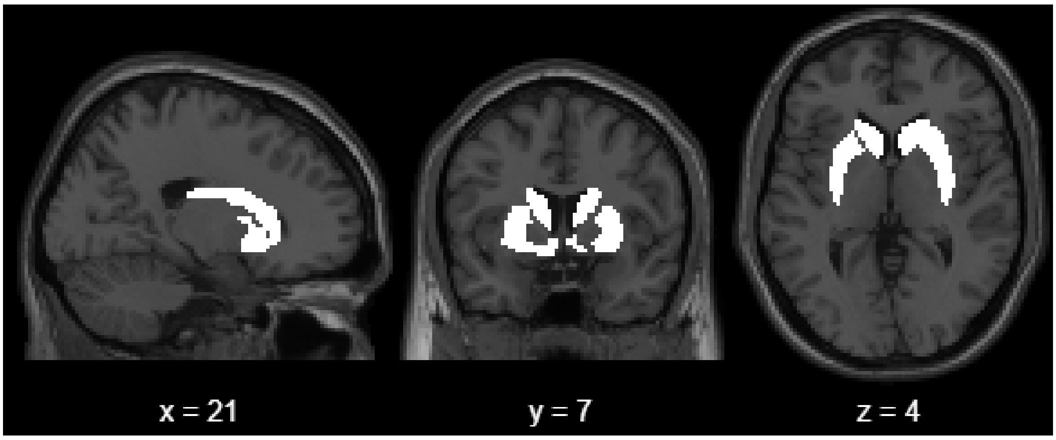
4.5.1. ROI Masks

ROI masks were created using the automatic anatomical labelling (AAL3v1) atlas (Rolls et al., 2020) accessed from the WFU-Pickatlas SPM tool (Maldjian et al. 2003; 2004). The striatum ROI consisted of the bilateral caudate, putamen, and nucleus accumbens while the ACC ROI consisted of bilateral ACC subgenual, ACC pregenual, and ACC supracallosal regions. ROI masks included 2615 voxels for striatum and 2557 voxels for ACC (Figure 26).

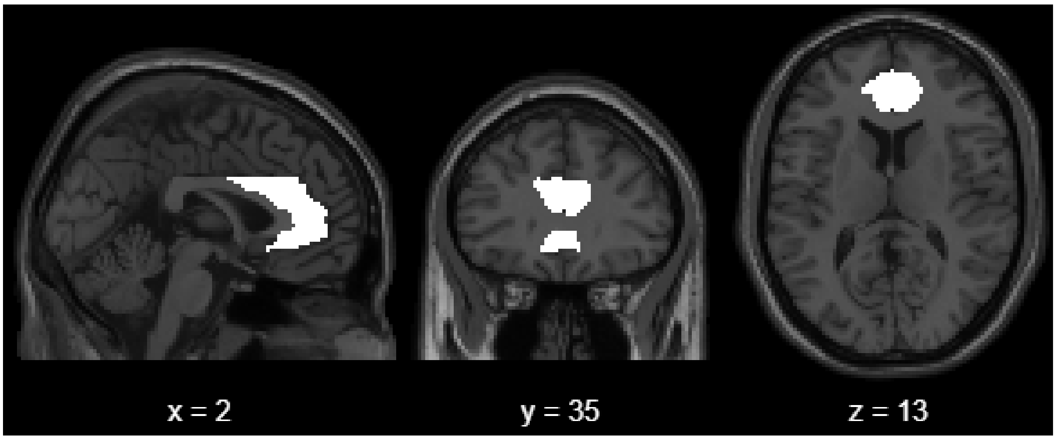
Figure 26

Striatum and ACC ROIs used in the ROI analysis

A. Striatum ROI



B. Anterior Cingulate Cortex ROI



Note. (A) The striatum ROI (2615 voxels) consisted of the bilateral caudate, putamen and nucleus accumbens. (B) The ACC ROI (2557 voxels) consisted of bilateral ACC subgenual, ACC pregenual and ACC supracallosal regions. The ROIs are represented on the “avg152T1.nii” template anatomical image from SPM12 library.

4.6. Results

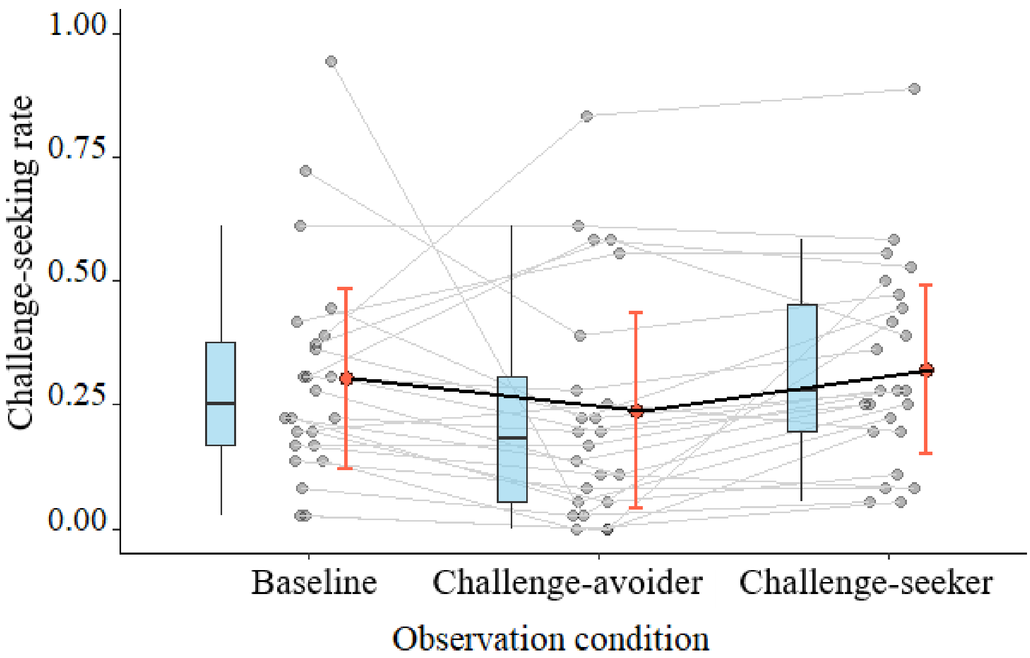
4.6.1. Behavioural Results

A 3 (Observation condition: baseline, challenge-seeker and challenge-avoider conditions) by 2 (Order: challenge-seeker confederate first, challenge-avoider confederate first) mixed effects ANOVA did not show a main effect of observation condition, $F(1.51, 33.3) = 2.28$, $p = .129$, $\eta_G^2 = 0.03$, confederate order, $F(1, 22) = 0.17$, $p = .683$, $\eta_G^2 = 0.01$, or their interaction, $F(1.51, 33.3) = 0.07$, $p = .885$, $\eta_G^2 = 0.001$.

Observing the challenge-seeker confederate increased participants' challenge-seeking rates (M = 0.32, SD = 0.2), compared to the baseline condition (M = 0.30, SD = 0.22) $t(24)$ = 0.46, p = .648, dz = 0.09, Holm adjusted alpha level = .03; and observing the challenge-avoider confederate decreased their challenge-seeking rates (M = 0.24, SD = 0.23) compared to the baseline condition, $t(24)$ = 1.30, p = .412, dz = 0.27, Holm adjusted alpha level = .05. However, these differences were not significant. The challenge-seeking rate in the challenge-seeker condition was significantly greater than the challenge-seeking rate in the challenge-avoider condition, $t(24)$ = 2.89, p = .025, dz = 0.59 (Holm adjusted alpha level = .02), replicating the previous results (Figure 27).

Figure 27

Mean challenge-seeking rate across observation conditions.



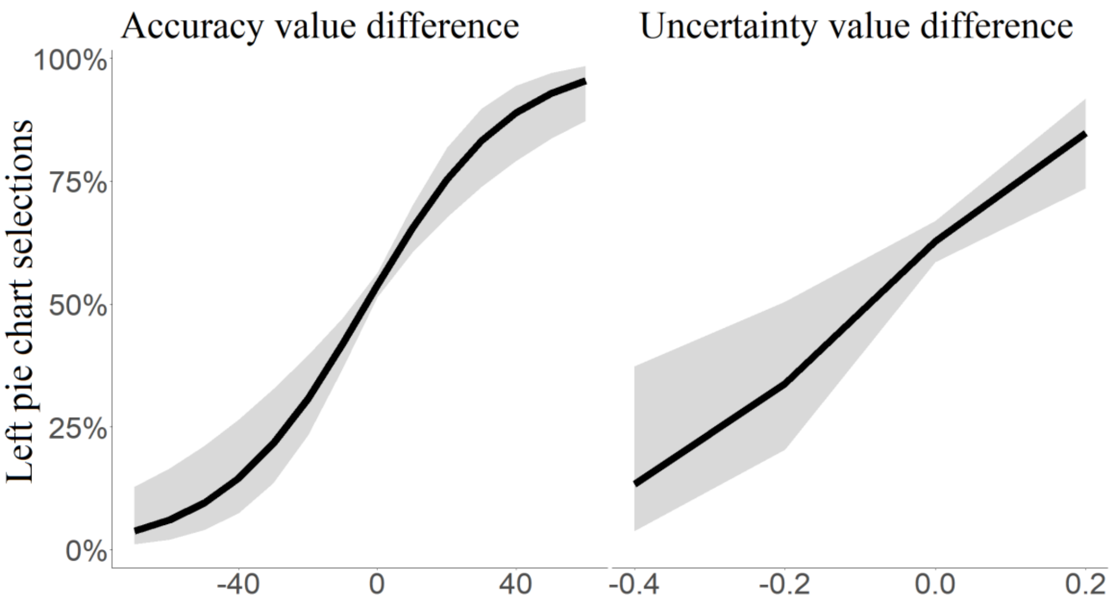
Note. Each participant's challenge-seeking rate for each observation condition was demonstrated with grey points with connecting light grey lines. Box plots show median challenge-seeking rates and lower & upper quartile values for each observation condition. Group averaged challenge-seeking rates for each observation condition were demonstrated with red dots with ± SE; and connected with black lines.

Consistent with the results of the online experiments, word problem selections were made based on the accuracy and uncertainty value of the word problem. A mixed-effects logistic regression model predicting word problem selection by accuracy and uncertainty values showed that participants decreased their difficult word problem choices as the accuracy difference between the options increased, $\beta = 0.05$, $SE = 0.01$, 95 % CI [0.03, 0.07], $p < .001$ (Figure 28). They were also more likely to choose the word problem with greater uncertainty value (with accuracy closer to 50%) as the difference between the uncertainty values of the two word problems increased, $\beta = 6.10$, $SE = 1.71$, 95% CI [2.75, 9.45], $p < .001$. Importantly, uncertainty resolution behaviours were not different across observation conditions, $F(2,46) = 2.61$, $p = .085$, $\eta_G^2 = 0.03$.

Participants' age, gender, or math anxiety were not correlated with the change in challenge-seeking rates across observation conditions (Appendix B).

Figure 28

Left pie chart selection by the difference between left and right pie charts' accuracy values and uncertainty values



Note. Participants were more likely to select the left pie chart with the increase in accuracy value difference (left panel) and the uncertainty value difference (right panel) between left and right pie charts.

4.6.2. fMRI Results

4.6.2.1. Main Effect of Selected Word Problem Difficulty

In both GLM-I and GLM-II, when comparing hard and easy choices (regardless of observation condition, e.g., hard choice> easy choice and easy choice > hard choice) there was no evidence of significant activations in the striatum ROI or the ACC ROI after family-wise error correction at the cluster level ($p < .05$). One sample t-test showed that participants' mean BOLD signal during hard choice > easy choice contrast was not greater than zero in the striatum ROI, $t(22) = 0.17$, $p = .868$, $d = 0.03$, or in the ACC ROI, $t(22) = 0.31$, $p = .758$, $d = 0.09$. Both statistical tests were corrected with the cluster level FWE threshold of $p < .05$. Contrasts comparing hard and easy choices created with choice-dependent and choice-independent parametric modulators (GLM-II) did not survive the FWE cluster level threshold ($p < .05$) for either ROI.

Exploratory whole brain analysis showed that hard choice > easy choice was associated with enhanced activation in the left medial superior frontal gyrus (peak coordinates: [-4, 30, 44], $k = 159$, $p = .004$, corrected with cluster level FWE threshold of $p < .05$) in GLM-I. Similarly, GLM-II indicated increased activation in the supplementary motor area for the same contrast (peak coordinates: [-2, 22, 52], $k = 303$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$). Note that these are anatomically overlapping regions, therefore, both GLMs indicated enhanced activity in similar brain areas (Table 4, Figure 29A). Increased activation in the right angular gyrus with peak coordinates 34, -58, 50 accompanied hard choice > easy choice contrasts (Figure 29B) in both GLMs ($k = 103$, $p = .032$ in GLM-I and $k = 130$, $p = .010$ in GLM-II, corrected with cluster level FWE threshold of $p < .05$). Furthermore, enhanced activation in the left cingulate gyrus (peak coordinates: [-12, -32, 38], $k = 109$, $p = .024$, corrected with cluster level FWE threshold of $p < .05$) was observed when easy choices were compared to hard choices (easy choice > hard choice) but only in GLM-II. Activations in easy choice > hard choice contrast or comparisons of hard and easy choices created with choice-dependent and choice-independent parametric modulators did not yield increased activations that survived the cluster level threshold of FWE ($p < .05$).

Table 4

Whole-brain analysis results for the main effects of selected word problem difficulty

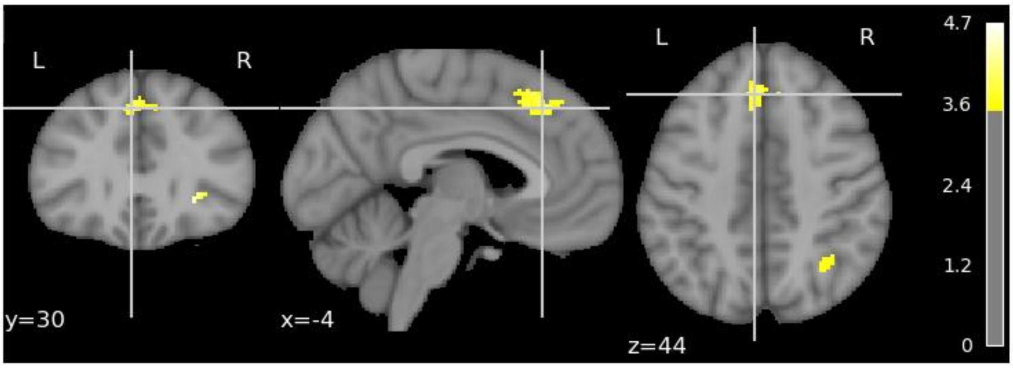
Contrast	**Brain region (peak)**	$P_{FWE\text{-}corr}$	**Cluster size**	**Peak *z* score**	**MNI coordinates x y z**
Hard > Easy (GLM-I)	L-Medial superior frontal gyrus	.004	159	3.51	-4 30 44
	R-Angular gyrus	.032	103	3.89	34 -58 50
Hard > Easy (GLM-II)	L-Supplementary motor area	<.001	303	3.55	-2 22 52
	R-Angular gyrus	.010	130	3.94	34 -58 50
Easy > Hard (GLM-II)	L-Cingulate gyrus	.024	109	4.77	-12 -32 38

Note. L = left and R = right. *P* values are corrected with cluster level FWE threshold of $p < .05$.

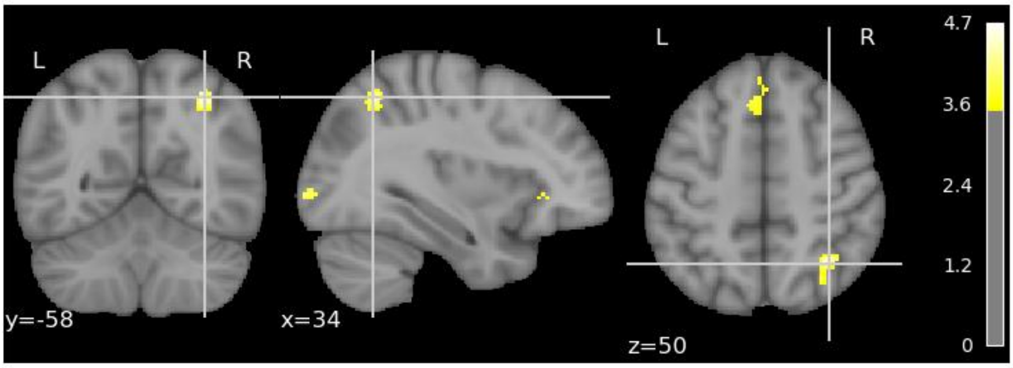
Figure 29

Whole-brain analysis results for the main effect of word problem difficulty

A.



B.



Note. Hard choice > easy choice contrast yielded enhanced activations in (A) the left medial superior frontal gyrus and (B) right angular gyrus. Only clusters that survived the FWE threshold of 0.05 were mapped.

4.6.2.2. Main Effect of Observation Condition

The ROI analysis comparing observation conditions regardless of selected problem difficulty did not yield enhanced responses in the striatum ROI or the ACC ROI for either GLM analysis. Clusters associated with the choice-dependent and choice-independent parametric modulators (GLM-II) did not survive the cluster level FWE threshold ($p < .05$). Individual one sample *t*-tests showed that participants' mean BOLD signal during the challenge-seeker > challenge-avoider contrast was not greater than zero in the striatum ROI, $t(22) = 1.10$, $p = .284$, $d = 0.33$ (corrected with cluster level FWE threshold of $p < .05$) or in the ACC ROI, $t(22) = 1.17$, $p = .256$, $d = 0.53$ (corrected with cluster level FWE threshold of $p < .05$). Similarly, mean voxel intensities in the striatum ROI and the ACC ROIs were not greater than zero for the challenge-seeker > baseline contrast (striatum ROI: $t(23) = 0.73$, $p = .473$, $d = -0.16$; ACC ROI: $t(23) = 0.39$, $p = .699$, $d = 0.17$, corrected with cluster level FWE threshold of $p < .05$) or for the challenge-avoider > baseline contrast (striatum ROI: $t(22) = 0.84$, $p = .410$, $d = 0.17$; ACC ROI: $t(22) = 1.36$, $p = .189$, $d = 0.72$, corrected with cluster level FWE threshold of $p < .05$).

Exploratory whole brain analysis indicated enhanced activations in the left inferior parietal gyrus (peak coordinates: [-36, -46, 42], $k = 430$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) in GLM-I, and the left middle occipital gyrus (peak coordinates: [28, -64, 34], $k = 426$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) in GLM-II when the challenge-avoider condition was compared to the baseline condition (challenge-avoider > baseline). Note that the left inferior parietal gyrus and left middle occipital gyrus are anatomically overlapping regions. Therefore, both GLMs indicated enhanced activations in similar brain regions for challenge-avoider > baseline contrast (Figure 30B).

When the challenge-seeker condition was compared to the baseline condition, enhanced activations in the left precuneus (peak coordinates: [-8, -68, 44], $k = 266$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) in GLM-I (Figure 30A) and the right precuneus (peak coordinates: [6, -52, 38], $k = 271$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) in GLM-II were observed. As shown in the MNI coordinates in Table 5, the activated clusters identified as right and left precuneus covered similar brain areas. Additionally, increased activation in the left middle occipital gyrus (peak coordinates: [-28, -66, 36], $k = 90$, $p = .038$, corrected with cluster level FWE threshold of $p < .05$) was observed when the challenge-seeker condition was compared to baseline, but only for GLM-II (Table 5). Clusters associated with other main effects of observation conditions (including the ones using choice-dependent and choice-independent parametric modulators) did not survive the FWE correction threshold of $p < .05$.

Table 5

Whole-brain analysis results for the main effects of observation condition

Contrast	**Brain region (peak)**	$P_{FWE\text{-}corr}$	**Cluster size**	**Peak *z* score**	**MNI coordinates x**	**y**	**z**

Avoider>Baseline (GLM-I)	L-Inferior parietal gyrus	<.001	430	4.47	-36 -46 42
Avoider>Baseline (GLM-II)	L-Middle occipital gyrus	<.001	426	4.54	-28 -64 34
Seeker>Baseline (GLM-I)	L-Precuneus	<.001	266	4.02	-8 -68 44
Seeker>Baseline (GLM-II)	R-Precuneus	<.001	271	4.06	6 -52 38
Seeker>Baseline (GLM-II)	L-Middle occipital gyrus	.038	90	4.68	-28 -66 36

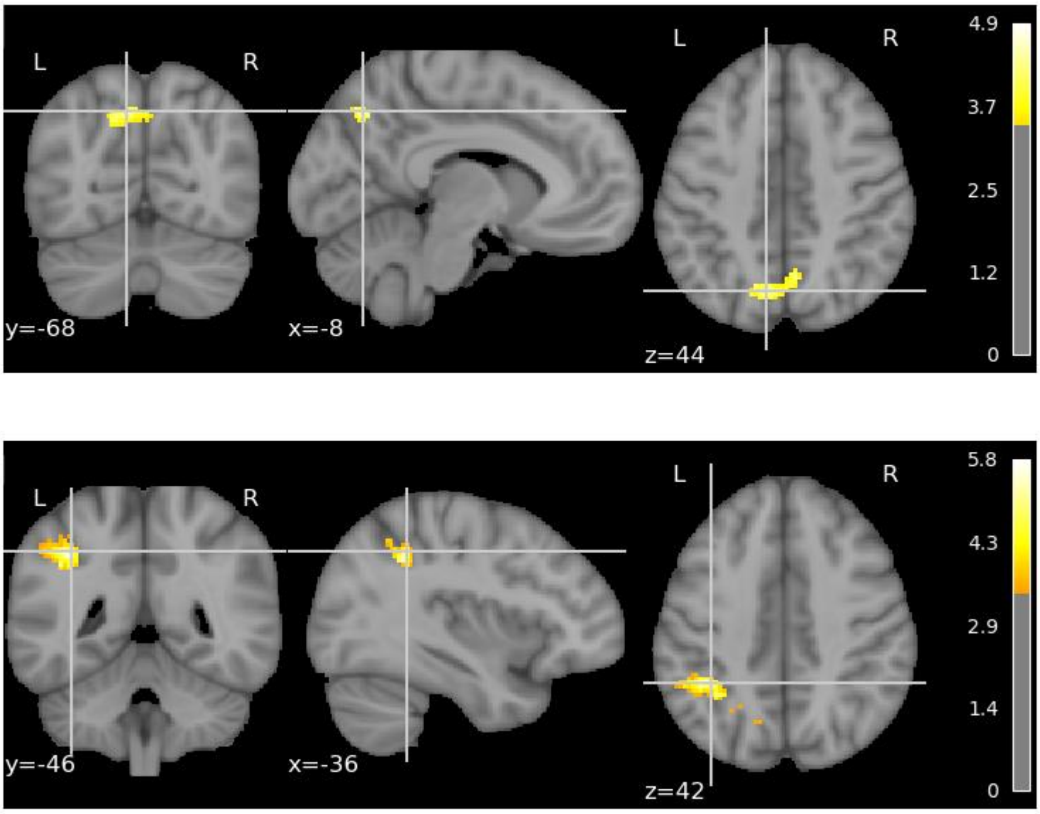
Note. L = left and R = right, seeker = challenge-seeker condition, avoider = challenge-avoider condition. *P* values are corrected with cluster level FWE threshold of $p < .05$.

Figure 30

Whole-brain analysis results for the main effect of observation condition

A.

B.



Note. (A) Seeker > Baseline contrast shows enhanced activation in left precuneus, (B) Avoider > Baseline contrast shows enhanced activation in left inferior parietal gyrus. Only clusters that survived the FWE threshold of $p < .05$ were mapped.

4.6.2.3. Interaction Effect of Selected Word Problem Difficulty and Observation Conditions

The striatum and ACC ROIs did not show increases in activation for the difference between the hard and easy choices across observation conditions (e.g., challenge-seeker hard choice - easy choice > challenge-avoider hard choice - easy choice). This was true for both GLMs and when the contrasts were created with choice-dependent and choice-independent parametric modulators. Individual one sample t-tests showed that the mean voxel intensity of each participant was not greater than zero in the striatum ROI or in the ACC ROI for the challenge-seeker hard choice - easy choice > challenge-avoider hard choice - easy choice contrasts (striatum ROI: $t(22) = 0.90$, $p = .380$, $d = 0.08$; ACC ROI: $t(22) = 0.88$, $p = .388$, $d = 0.19$; both corrected for FWE threshold of $p < .05$), the challenge-seeker hard choice - easy choice > baseline hard choice - easy choice contrast (striatum ROI: $t(23) = 0.33$, $p = .743$, $d = 0.03$; ACC ROI:

$t(23) = 1.00$, $p = .326$, $d = 0.14$; both corrected for FWE threshold of $p < .05$) and between challenge-avoider hard choice - easy choice > baseline hard choice - easy choice contrasts (striatum ROI: $t(22) = 1.18$, $p = .249$, $d = 0.13$; ACC ROI: $t(22) = 1.23$, $p = .234$, $d = 0.31$; both corrected for FWE threshold of $p < .05$).

The whole brain analysis indicated that the difference between hard and easy choices across challenge-seeker and challenge-avoider conditions (challenge-seeker hard-easy choice > challenge-avoider hard-easy choice) was accompanied with increased activity in the left superior temporal gyrus (peak coordinates: [-62, -34, 18]) for both GLM-I ($k = 142$, $p = .005$, corrected with cluster level FWE threshold of $p < .05$) and GLM-II ($k = 117$, $p = .014$, corrected with cluster level FWE threshold of $p < .05$) (Figure 31A). The negative contrast (challenge-avoider hard-easy choice > challenge-seeker hard-easy choice) was accompanied by an increase in the left superior frontal gyrus activity (peak coordinates: [-2, 36, 44], $k = 91$, $p = .043$, corrected with cluster level FWE threshold of $p < .05$) but only in GLM-I (Table 6, Figure 31B). Other interaction effects (including the ones consisting of the choice-dependent and choice-independent parametric modulators) did not survive the cluster-level FWE correction ($p < .05$).

Table 6

Whole-brain analysis results for the interaction effects of selected word problem difficulty and observation conditions.

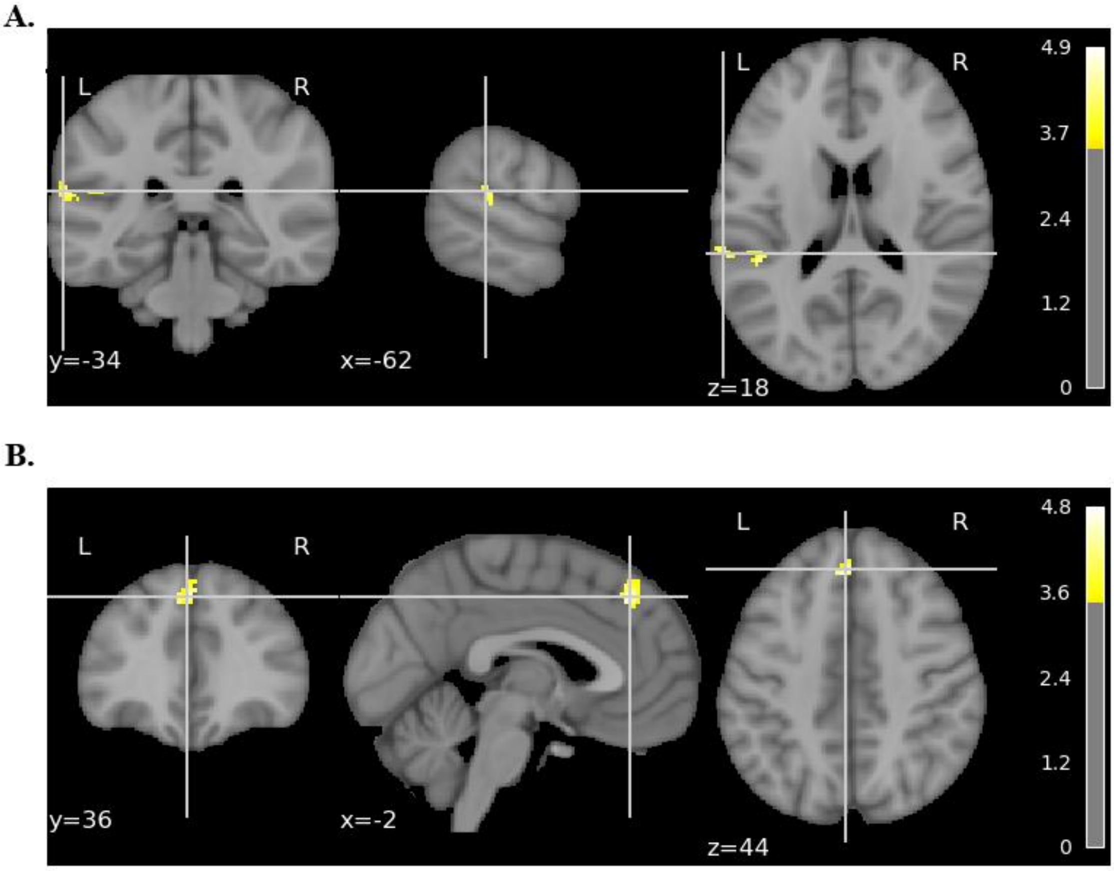
Contrast	Brain region (peak)	$P_{FWE\text{-}corr}$	Cluster size	Peak *z* score	MNI coordinates x	y	z
Seeker H-E > Avoider H-E (GLM-I)	L-Superior temporal gyrus	.005	142	3.98	-62	-34	18
Seeker H-E > Avoider H-E (GLM-II)	L-Superior temporal gyrus	.014	117	4.05	-62	-34	18

Avoider H-E > Seeker H-E (GLM-I)	L-Superior frontal gyrus	.043	91	3.95	-2 36 44	

Note. L = left, R = right, seeker = challenge-seeker condition, avoider = challenge-avoider condition. *P* values are corrected with cluster level FWE threshold of $p < .05$.

Figure 31

Whole-brain analysis results for the interaction effects of word problem difficulty and observation conditions



Note. (A) Challenge-seeker hard - easy choice > challenge-avoider hard - easy choice revealed increased activation in the left superior temporal gyrus (B) challenge-avoider hard – easy choice > challenge-seeker hard - easy choice revealed increased activation in the left superior frontal gyrus activity. Only the clusters that survived the FWE threshold of $p < .05$ were mapped.

4.6.2.4. Effects of Choice Difficulty Between and Within Observation Conditions

In GLMs I and II, the striatum ROI and the ACC ROIs did not indicate significant activations for the simple main effect of hard choice > easy choice contrast in any observation condition (e.g., baseline hard choice > baseline easy choice). Additionally, hard choice across observation conditions (e.g.., challenge-seeker hard choice > challenge-avoider hard choice) or easy choice across observation conditions (e.g., challenge-seeker easy choice > challenge-avoider easy choice) did not yield any activation increase in the striatum or ACC ROIs. The ROI analysis did not indicate a cluster that survived the cluster level FWE ($p < .05$) when contrasts included the choice-dependent and choice-independent parametric modulators.

Exploratory whole-brain analysis conducted on word problem difficulty within observation conditions indicated that the hard choice > easy choice contrast at challenge-avoider condition was accompanied with an enhanced bilateral supplementary motor area activation (left hemisphere: peak coordinates: [-4, 24, 56], $k = 443$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$; right hemisphere: peak coordinates: [12, 22, 58], $k = 98$, $p = .040$, corrected with cluster level FWE threshold of $p < .05$). GLM-II additionally indicated enhanced activation in the right insular cortex (peak coordinates: [30, 22, 2], $k = 100$, $p = .037$, corrected with cluster level FWE threshold of $p < .05$) and the right angular gyrus (peak coordinates: [32, -58, 50], $k = 109$, $p = .026$, corrected with cluster level FWE threshold of $p < .05$) for this contrast (Table 7, Figure 32). On the other hand, the hard choice > easy choice contrast revealed increased activations in the bilateral cerebellum (Figure 32) (left hemisphere: peak coordinates: [-36, -64, -30], $k = 219$, $p < .001$, corrected with cluster level few threshold of $p < .05$; right hemisphere: peak coordinates: [30, -60, -30], $k = 225$, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) and the right inferior parietal gyrus (: peak coordinates: [48, -42, 56], $k = 125$, $p = .007$, corrected with the cluster level FWE threshold of $p < .05$) for both GLMs (please refer to Table 7 for peak coordinates, cluster sizes and p values of this contrast in GLM-II).

Contrasts comparing the word problem difficulties between the observation conditions indicated that hard choice in the challenge-avoider condition > hard choice in the baseline condition was accompanied by an enhanced activation in the left inferior parietal gyrus (Figure 33) (peak coordinates: [-40, -48, 40], k = 222, $p < .001$, corrected with cluster level FWE threshold of $p < .05$) and in the left inferior temporal gyrus (peak coordinates: [-54, -54, -20], k = 90, p = .054, FWE corrected at cluster level) (please refer to Table 8 for GLM-II results). Furthermore, increased activity in the left superior parietal gyrus (peak coordinates: [-30 -74 52], k = 100, p = .024, corrected with cluster level FWE threshold of $p < .05$) was observed for the hard choice in the challenge-seeker condition > hard choice in the baseline condition contrast, but only for GLM-II. Clusters associated with other simple main effects (including the ones with choice-dependent and choice-independent parametric modulators) did not survive the cluster level FWE correction threshold of $p < .05$.

Table 7

Whole-brain analysis results for selected word problem difficulty within observation conditions

Contrast	Brain region (peak)	$P_{FWE\text{-}corr}$	Cluster size	Peak *z* score	MNI coordinates x y z
Seeker Hard > Easy (GLM-I)	L-Cerebellum	<.001	219	4.76	-36 -64 -30
	R-Cerebellum	<.001	225	4.19	30 -60 -30
	R-Inferior parietal gyrus	.007	125	3.78	48 -42 56
Seeker Hard > Easy (GLM-II)	L-Cerebellum	.001	186	4.77	-36 -64 -30

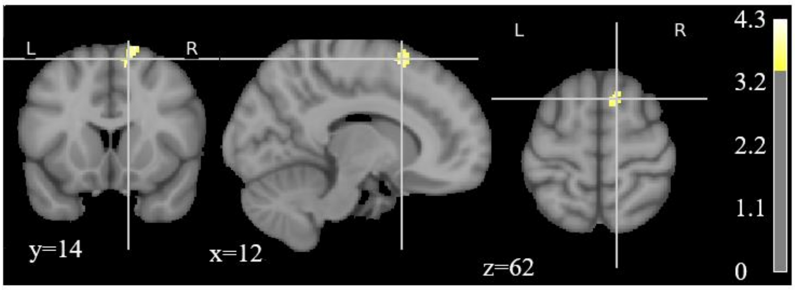
	R-Cerebellum	<.001	204	4.18	30 -64 -32
	R-Inferior parietal gyrus	.008	124	3.82	48 -42 56
Avoider Hard>Easy (GLM-I)	L-Supplementary motor area	<.001	443	4.57	-4 24 56
	R-Supplementary motor area	.040	98	4.37	12 22 58
Avoider Hard>Easy (GLM-II)	L-Supplementary motor area	<.001	393	4.39	-4 24 54
	R-Insular cortex	.037	100	4.20	30 22 2
	R-Angular gyrus	.026	109	3.77	32 -58 50

Note. L = left and R = right, seeker = challenge-seeker condition, avoider = challenge-avoider condition.

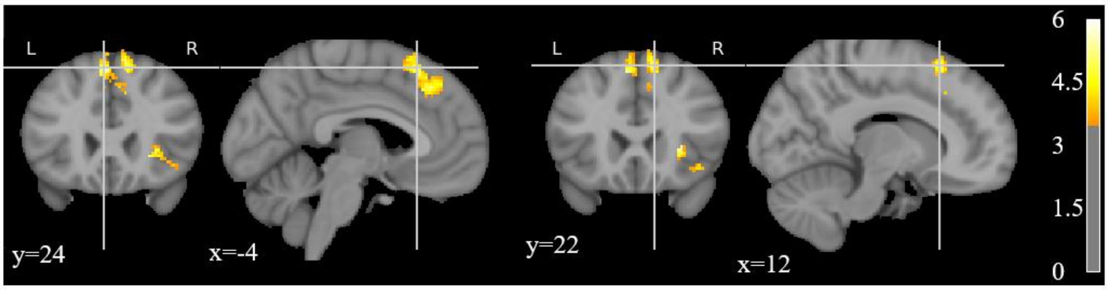
Figure 32

Whole-brain analysis results for the hard choice > easy choice contrasts for each observation condition

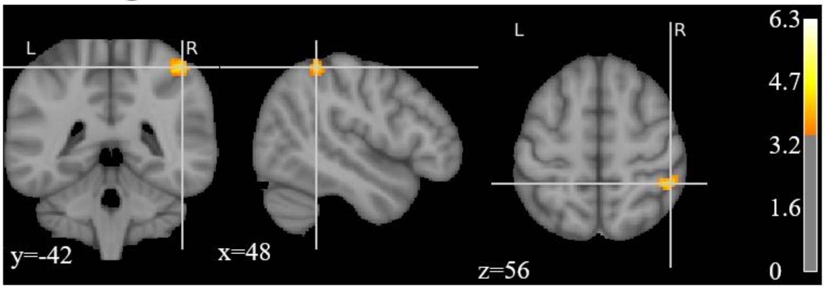
A. Baseline condition

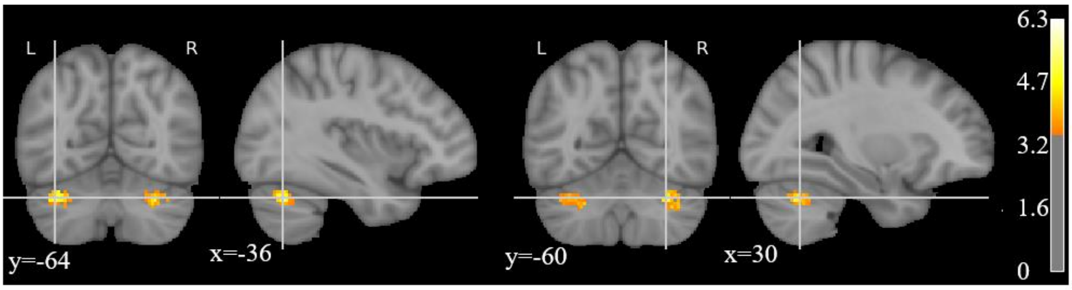


B. Challenge-avoider condition



C. Challenge-seeker condition





Note. Hard >easy word problem choices at (A) baseline (B) challenge-avoider and (C) challenge-seeker conditions. Hard choice at baseline and challenge-avoider conditions were accompanied with supplementary motor area activations while the same contrast was associated with enhanced activity in the bilateral cerebellum and left inferior parietal gyrus for the challenge-seeker condition. Only the clusters that survived the FWE threshold of $p < .05$ were mapped.

Table 8

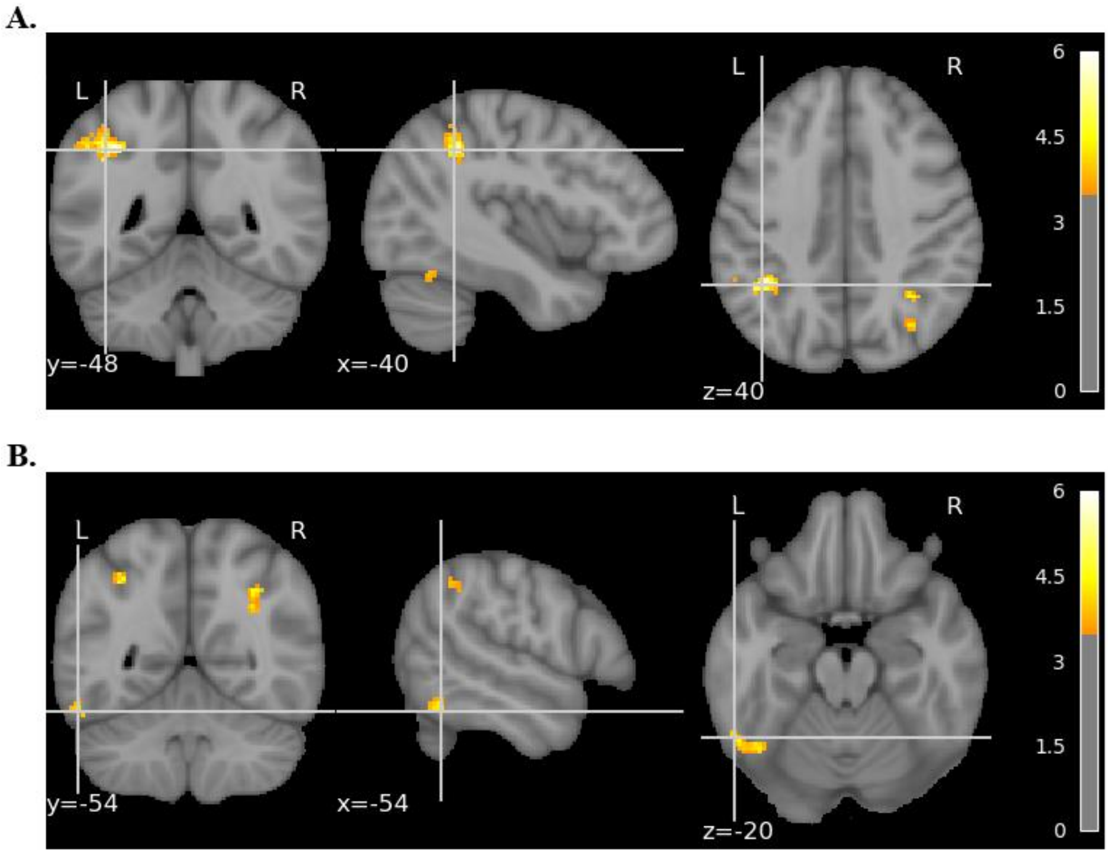
Whole-brain analysis results for selected word problem difficulty between observation conditions

Contrast	Brain region (peak)	$P_{FWE\text{-}corr}$	Cluster size	Peak z score	MNI coordinates x	y	z
Avoider Hard> Baseline Hard (GLM-I)	L-Inferior parietal gyrus	<.001	222	4.56	-40	-48	40
	L-Inferior temporal gyrus	.054	90	3.78	-54	-54	-20
Avoider Hard> Baseline Hard (GLM-II)	L-Inferior parietal gyrus	<.001	249	4.54	-38	-46	40
Seeker Hard> Baseline Hard (GLM-II)	L-Superior parietal gyrus	.024	100	4.10	-30	-74	52

Note. L = left and R = right, seeker = challenge-seeker condition, avoider = challenge-avoider condition

Figure 33.

Whole-brain analysis results for the hard choice at challenge-avoider condition > hard choice at baseline condition



Note. Hard choice in the challenge-avoider condition > hard choice in the baseline condition contrast shows enhanced activation in the (A) left inferior parietal gyrus and (B) inferior temporal gyrus. Only clusters that survived the FWE threshold of $p < .05$ were mapped.

4.6.3. Conclusions

The behavioural results replicated the previous behavioural experiments. Observing the challenge-seeker confederate increased participants' baseline challenge-seeking tendencies, while observing the challenge-avoider confederate did not have a significant influence on it.

ROI analysis did not show significantly increased activation in the striatum or the ACC as a function of word problem difficulty, observation condition or their interaction. Therefore, the hypothesis regarding the reward related (striatal) and resource recruitment related (ACC) activations in response to hard choices, in general and in challenge-seeker condition, was not supported.

Exploratory whole brain analyses indicated enhanced activations in the left medial superior frontal gyrus (in GLM-II it was the anatomically overlapping neighbour: supplementary motor area) and the angular gyrus for hard choices compared to easy choices. The medial superior frontal gyrus has been previously linked to decision conflict under risk and uncertainty (Rushworth et al., 2004; Pochon et al., 2008; Venkatraman et al., 2009) and the angular gyrus has been associated with complex abstract thinking such as mathematical reasoning, number processing and multiplication tasks (Zago & Tzourio-Mazoyer, 2002; Dehaene et al., 2003). Possibly, the medial superior frontal gyrus activation represented the decision conflict participants experienced while choosing between two similarly attractive hard and easy word problem choices. On the other hand, the angular gyrus activation was likely related to participants' preparation for math-related engagement.

Furthermore, obtained results indicated that challenge-avoider and challenge-seeker conditions (compared to baseline condition) were associated with enhanced inferior parietal and precuneus activities extending to the middle occipital regions; regions previously co-activated during tasks requiring social cognitive processing (Gobbini et al., 2007; Sommer et al., 2007; Van Veluw & Chance, 2014) or mental calculation (Zago & Tzourio-Mazoyer, 2002). Therefore, compared to the baseline condition, both challenge-seeker and challenge-avoider conditions represented similar activation patterns. Activation patterns observed for the interaction effects provided further support for this claim. The difference between the hard and easy choices for the challenge-seeker condition compared to the challenge-avoider condition recruited similar brain regions as its negative contrast (challenge-avoider hard choice - easy choice > challenge-seeker hard choice - easy choice).

When hard choices in the challenge-seeker and challenge-avoider conditions were examined separately, enhanced activations in the bilateral cerebellum and supplementary motor area were observed. These activations possibly reflected the motor response that participants engaged in when selecting word problems. On the other hand, the inferior parietal gyrus activation (challenge-seeker condition) and the angular gyrus/insula activation observed for the challenge-seeker and challenge-avoider conditions likely represented the math-related activity involvement as these activations were observed for the main effect of word problem difficulty as well (hard > easy).

Chapter 5: General Discussion

5.1. Summary of Key Findings

The results from all experiments consistently showed that participants were challenge avoidant at baseline. Although watching a challenge-avoider confederate did not spark a change in the observer's challenge-seeking tendencies, watching a challenge-seeker in general did. Participants chose to be engaged in difficult word problems more frequently after observing a challenge-seeker doing the same. Importantly, this behavioural shift was not significantly associated with any change in participants' perceptions of the difficulty of the word problems, confidence in their ability, or likability of the confederate observed. Challenge-seeking tendencies and proneness to the social contagion of challenge-seeking were significantly associated with mastery-approach goals and trait motivation (to-know) scores, but not with other achievement goals, other subscales of trait motivation, participant demographics (age and gender), math self-concept or self-reported math anxiety.

The current thesis also revealed the neural correlates underlying challenge-seeking behaviours and their social contagion. Participants' challenge-seeking behaviours were associated with an increased activation in the medial superior frontal gyrus; a region previously associated with decision conflict (Pochon et al., 2008) and choices incongruent with one's usual behavioural tendencies (Venkatraman et al., 2009). Moreover, the social contagion of challenge-seeking was found to be related to increased activations in the superior temporal and superior frontal gyri, inferior parietal gyrus, angular gyrus, and precuneus, regions previously reported during social cognitive processing (Hein & Knight, 2008; Wolf et al., 2010).

5.2. Behavioural Findings

5.2.1. Challenge Avoidance at Baseline

Generally lower challenge-seeking rates at baseline, ranging from .12 to .30, suggested that participants exhibited a predisposition towards avoiding challenges before any experimental manipulation took place.

These results conflict with the previous research which indicated a preference for moderately difficult tasks due to their potential for learning and satisfaction of individuals' need for competence (Jagacinski et al., 2008; Legault, 2017; Ryan & Deci, 2020).

On the other hand, the challenge-avoidant tendencies of the participants are in line with individuals’ tendency to avoid negative outcomes (Dubey & Griffiths, 2020). Failure and negative feedback are perceived as aversive and usually avoided (Nicholls, 1984; Mueller & Dweck, 1998; Lee & Kim, 2014).

Furthermore, individuals are inclined to prefer less effortful options (Law of less work theory, Hull, 1943). If the reward is equal, the organism chooses a path that requires the minimum number of resources spent. The decision cost (mental processes required for decision making such as attention) is at the heart of the rational (economic) choices that weigh the expected benefits against the foregone (Smith & Walker, 1993). Tasks that involve demanding activities, such as repeated task switching, frequent shifts in attention (Kool et al., 2010), or the inclusion of challenging math problems (Rege et al., 2021), tend to be unpopular and actively avoided (Inzlicht et al., 2018). These tasks are generally rated as having significantly lower subjective value, and individuals are willing to forgo higher monetary rewards to avoid engaging in them (Apps et al., 2015; Westbrook et al., 2013). The challenge-avoidance behaviours observed in the current research could reflect a reduced subjective value of challenging options. Participants knew they would not get rewarded for choosing difficult word problems/ or for their performance in them. Therefore, they selected the options requiring minimum cognitive resources.

5.2.2. Social Contagion in Challenge-Seeker Condition

Increased tendency to select harder word problems after observing the challenge-seeker confederate is in line with the theories suggesting that motivation can spread via vicarious learning (Bandura, 1977). Wild et al. (1992) proposed that this behavioural change may arise from perceptions of others' intrinsic motivation, which in turn create specific expectations regarding the quality of their engagement and influence individuals' own levels of intrinsic motivation. Obtained results contribute to the existing literature that demonstrated the social contagion of achievement motivation (Wild & Enzle, 2002; Krishen, 2013; Frenzel et al., 2019), preference for challenge (Altermatt & Pomerantz, 2003) and other concepts similar to challenge-seeking, such as effort exertion. For instance, Desender and colleagues (2016) revealed that participants exerted greater mental effort in a Go/No-Go task after they watched the person sitting next to them exerting greater mental effort for the same task but at a higher difficulty level.

Crucially, unlike most social contagion experiments, the experiments reported here studied the social contagion between strangers, not between friends or family. This feature allowed to control for the possible confounds of complex emotional factors or predictions based on past experiences. For instance, the social contagion manipulation used in the challenge-seeking task possibly would not work if the participants saw their friend, who usually acts in a challenge-avoiding fashion, seeking challenges during the experiment. For the same reason, the likeability manipulation (in the Likeability Experiment, Chapter 3) might not have been applied in a controlled fashion. Therefore, although the obtained results might not be generalised to social contagion across friends, the experiments reported here provide support for the previous literature indicating the social contagion of intrinsic motivation (Friedman et al., 2010; Scarapicchia et. al., 2013) and risk-seeking (Suzuki et al., 2016; Reiter et al., 2019) between strangers.

One might argue that the increased challenge-seeking behaviour after watching a challenge-seeker confederate is simply an example of imitation, such as face rubbing, or leg shaking (Chartrand & Bargh, 1999). Imitation is believed to be represented in mirror neurons, that selectively respond to the observation and execution of actions (Iacoboni, 2005). Mirror neurons contribute to the social contagion of challenge-seeking, especially when understanding the intentions and actions of others and feeling the excitement or any other emotion they express. However, mirror neurons alone cannot fully account for the social contagion of challenge-seeking. The high-level decision-making involved in seeking challenges requires weighing up different paths and calculating the amount of effort needed for each. It is more likely that the social contagion of challenge-seeking is the result of complex interactions between mirror neurons and higher-order brain regions. Increased activations in superior frontal regions, when participants sought challenges after observing the challenge-seeker confederate, provide support for this argument.

5.2.3. Social Contagion in Challenge-Avoider Condition

Contrary to the hypothesis, observing a challenge-avoider did not decrease participants' willingness to seek challenges. One potential explanation may be the floor effect. Participants’ inclination to avoid challenges at baseline might have left limited room for further decrease in such behaviours.

Nonetheless, there is a possibility that observing challenge-seeker and challenge-avoider confederates had an uneven impact on participants' tendencies to seek challenges. Future research should explore this potential asymmetry through a design that avoids the limitations associated with the floor effect.

5.2.4. The Influence of Cognitive Load on the Social Contagion of Challenge-Seeking

The behavioural shift across the challenge-seeker and challenge-avoider conditions was not replicated (in terms of statistical significance) in Experiment 4 and Likeability Experiment. One simple explanation is the lack of statistical power. Although the effects were not significant, the participants' behavioural patterns were the same in these experiments. Another possible reason for not replicating the results might be the cognitive load required for switching between giving ratings and choosing word problems interfered with participants' performance in the challenge-seeking task. A similar preference for tasks with less task switching was observed by Kool and colleagues (2010) as well. Additionally, performance decrements and increased reaction times in trials that followed perceived difficulty and self-confidence ratings, compared to the ones that preceded them, support this possibility. According to Allport and Wylie (2000) switching to a new task may take a longer reaction time, possibly due to an interference from the previous task-related processing or the time taken by the control processes signalling a change in task. Perhaps the task-switching element took up the cognitive resources required for the decision-making processes. Participants, not having sufficient cognitive resources to weigh the costs and benefits of each word problem, just went with the least effortful option. It is a plausible explanation considering the previous research indicating reduced risk-taking tendencies in response to increased cognitive load (Benjamin et al., 2013; Deck & Jahedi, 2015).

5.3. Neural Correlates of Challenge-Seeking Contagion

Contrary to the predictions, the social contagion of challenge-seeking behaviour was not linked to activity changes in the striatum or ACC. However, exploratory whole-brain analyses indicated possibly higher social cognitive processing during challenge-seeker and challenge-avoider conditions, compared to baseline. Furthermore, greater dmPFC activation in response to hard word problem selection may have represented a decision conflict or selection of options incongruent with participants' general challenge-seeking tendencies.

5.3.1. Social Cognitive Processing in the Observation Conditions

Greater activations in the superior temporal sulcus (STS), superior frontal gyrus, inferior parietal gyrus, and precuneus, which were previously linked to social cognitive processing (Amodio & Frith, 2006) such as the ability to attribute mental states of others (theory of mind) (Sommer et al., 2007), accompanied participants' overall word problem choices and in particular hard word problem choices, during challenge-seeker and challenge-avoider conditions.

A closer look at the main effects of observation conditions showed that the challenge-avoider condition (was accompanied by enhanced activation in the inferior parietal gyrus, a region frequently reported in language processing (Broca's area) but also in imitation (Heiser et al., 2003; Iacoboni, 2005) and theory of mind (Sommer et al., 2007). On the other hand, the challenge-seeker condition showed enhanced precuneus activity, a region associated with a wide range of complex processes such as episodic memory retrieval, self-referential processing and consciousness (Cavanna & Trimble, 2006) in addition to social cognitive processing (Hein & Knight, 2008; Wolf et al., 2010). Perhaps the precuneus activation signalled the need for higher-order processing in the challenge-seeker condition. However, involvement of the inferior parietal gyrus in complex social cognitive processing, such as learning about others' risk preferences, indicated that the inferior parietal gyrus is recruited for complex tasks as well (Suzuki et al., 2016). Besides, the co-activation of the precuneus and inferior parietal gyrus for both complex tasks requiring mental calculation (Zago & Tzourio-Mazoyer, 2002) and less complex mental imagery tasks (Iseki et al., 2008) means that the inferior and parietal gyrus and precuneus have similar functions. Therefore, the current results cannot suggest that the challenge-seeker condition was associated with a greater social cognitive processing. Therefore, the only claim based on the obtained results would be that the activation of higher-order brain regions previously linked to social cognition was observed in the challenge-seeker and challenge-avoider conditions, compared to the baseline.

The hard choices in challenge-seeker and challenge-avoider conditions showed enhanced activations in regions associated with social cognitive processing as well. For instance, STS, which showed increased activation during hard choices in the challenge-avoider condition, has been shown to play an important role in imitation by sending higher-order visual descriptions of observed action to the frontoparietal mirror neuron system and matching the imitative plan sent from the frontoparietal mirror neuron system with the observed action (Iacoboni, 2005; Molenberghs et al., 2009). On the other hand, the superior frontal gyrus was linked to self- and other-oriented judgments (Ochsner et al., 2004) and empathic forgivability judgments (Farrow et al., 2001). These results strengthen the possibility of greater social cognitive processing at play when participants were seeking challenges after they observed the challenge-seeker confederate.

5.3.2. Choosing Hard Problems: A Change in Preference or A Decision Conflict

An increased activity was observed in the medial superior frontal gyrus, more commonly known as the dorsomedial prefrontal cortex (dmPFC) during the hard choices compared to the easy ones. These findings may be interpreted as an example of choosing between two equally valued options (response conflict) or a change in participants' usual preference.

Hard choices were expected to be linked to enhanced activity in the ACC due to its previously reported role in high conflict decision-making tasks (Pochon et al., 2008) and risky choices (Ernst et al., 2004; Sanfey et al., 2003). Although ROI analysis did not indicate such activity in the ACC, exploratory whole-brain analysis showed enhanced activity in the dmPFC. This region is not only anatomically adjacent to the ACC but shows functional similarity to ACC (Rushworth et al., 2004). Previous research linked increased dmPFC and ACC activity to decision conflicts (Pochon et al., 2008) and decision-making under risk and uncertainty (Rushworth et al., 2004; Venkatraman et al., 2009). For instance, greater ACC and dmPFC activity was reported when male subjects were asked to choose between two highly attractive female faces similar in desirability, compared to one attractive face and one unattractive face (Pochon et al., 2008).

Importantly, increased dmPFC activation in hard choices supports previous research that links dmPFC activity to changes in participants' usual preferences. Venkatraman and colleagues (2009) reported increased dmPFC activity when subjects made choices opposite to their usual pattern of responses. Using an economic decision-making task that required participants to select from gain-maximising, loss-minimising and probability-maximising gambles, researchers determined each subjects' gamble preference by recording their gamble selection frequencies. They found that the dmPFC activation was greater when participants who usually selected gain-maximising or loss-minimising gambles selected a probability-maximising gamble (Venkatraman et al., 2009). Considering the challenge-avoiding tendencies of the participants at baseline, it is plausible to think that the dmPFC activity was related to the change in word problem difficulty preference.

5.4. Implications

The current research is of vital importance for taking a step in studying the social contagion of challenge-seeking behaviour. Considering the facilitative role of challenge-seeking behaviour on skill development (Chase et al., 2021) and creative thinking (Li, 2015), its spread would support mental well-being and achievement in schools and workplaces. More specifically, the promotion of social contagion of challenge-seeking can lead to the reduction of negative emotions towards learning and set a mastery achievement-oriented atmosphere in schools.

Fear of failure is associated with negative educational outcomes (Beilock et al., 2010). In learning environments that value challenge-seeking behaviour, failures are considered opportunities to master skills (Dweck & Leggett, 1988). Therefore, students who are exposed to learning environments with a pro-challenge-seeking culture would adopt a challenge-approach behaviour over time. As this challenge-seeking culture is internalised, failures would be less likely to induce much anxiety.

Challenge-seeking contagion would also help individuals learn about themselves. Being in the same environment as challenge-seekers can inspire individuals to expand their understanding of what is possible and gain new insights into their own capabilities (Yeager et al., 2019). It would encourage them to strive for excellence, setting higher standards for themselves and their achievements. It might even introduce a competition at moderate levels which would motivate individuals to continuously improve their skills (Franken & Brown, 1995).

5.5. Exploratory Findings

5.5.1. Challenge-Seeking and Achievement Goals

The correlation between achievement goals and challenge-seeking behaviours reported in the current research does not fully support the previous research (Dweck & Leggett, 1988; Elliot & Harackiewicz, 1996; Jagacinski, 2008). Contrary to the predictions, mastery-approach achievement goals were not associated with overall greater challenge-seeking tendencies and performance-avoidance achievement goals were not correlated with the social contagion of challenge-seeking behaviour. Instead, mastery achievement goals were positively correlated with the social contagion of challenge-seeking.

Previous research reported that mastery achievement goals were associated with greater challenge-seeking behaviours for skill improvement (Jagacinski et al., 2008, Abercrombie et al., 2022). Furthermore, based on the sensitivity to social cues of those having performance-approach achievement goals (e.g., making self-competence judgments based on others' competence), greater susceptibility to the social contagion effect was expected in those with performance-approach achievement goals. However, neither was observed in the current experiment, possibly due to a low statistical power.

The positive correlation between mastery achievement goals and susceptibility to the social contagion of challenge-seeking was unexpected considering the previous research claiming that those with mastery achievement goals rely on self-referenced standards, rather than other-referenced ones (Ames & Archer, 1988). Although unexpected, the observed positive correlation is consistent with previous work showing that those with mastery achievement goals engage in social comparison in class to assess their skills for purposes of academic self-improvement (Régner et al. 2007; Tian et al., 2017).

5.5.2. Uncertainty Resolution

An exploratory analysis indicated that participants preferred word problems in which their chance of success was uncertain (closer to 50% chance of success). Based on the early research in curiosity, uncertainty resolution is rewarding. Individuals preferred to expose novel blurred pictures compared to familiar blurred pictures (Nicki, 1970) and showed longer EEG desynchronization duration when viewing the novel blurred pictures (Berlyne & Borsa, 1968). More recent work confirms that revealing the unknown option is rewarding by demonstrating increased striatal activation in response to curiosity-inducing trivia questions (Gruber et al., 2014; Kang et al., 2009) or magic tricks (Lau et al., 2020). According to the reward-learning framework of knowledge acquisition (Murayama, 2022), once an individual becomes aware of a knowledge gap (i.e., uncertainty), the ‘inherent reward’ value of the missing information is calculated. If the reward value is high, the individual engages in information-seeking behaviour.

The preference for word problems with greater uncertainty value did not change across observation conditions. Therefore, the behavioural shift in word problem choices across observation conditions is unlikely to be related to their uncertainty values. These findings are in alignment with the idea that uncertainty resolution and challenge-seeking are different concepts. Both are active behaviours that are influenced by the expected value of the goal. In the context of uncertainty resolution, this pertains to the expected value of the missing information (Murayama, 2022). Regarding the challenge-seeking behaviour, it is the expected value of the quality of involvement (Wild et al., 1992). Therefore, although the behavioural patterns are similar, the goals are different. While the uncertainty resolution aims to explain the environment (Redmond, 2015), challenge-seeking aims to satisfy a sense of achievement and competence.

5.6. Limitations

The experiments reported here have a couple of limitations. Firstly, the challenge-seeking task did not employ a feature that would separate challenge-seeking behaviour from similar concepts such as mental effort. Secondly, challenge-seeking behaviour was assessed using the willingness to engage in a math task, which limits the results’ generalisability.

The current study operationalised challenge-seeking behaviour as the selection of difficult word problems over easier ones. However, other achievement-related concepts are measured in a similar fashion. For instance, effort, resilience, perseverance, and uncertainty resolution were often measured using a high-demand task involvement. The current research attempted to use a paradigm that would differentiate challenge-seeking from similar concepts. For instance, by not involving performance-contingent feedback, possible recruitment of perseverance or resilience-related processing was prevented. Furthermore, participants did not see the content of the word problems as this would lead to the engagement of effort-related cognitive processing. Unfortunately, hiding the content of the word problems and only showing their accuracy value might have sparked curiosity in participants. As consistently reported in each experiment reported here, participants were more likely to choose the word problems with high uncertainty values (values closer to 50% accuracy). The preference for uncertainty resolution was not affected by confederates' behavioural tendencies and therefore the observed results were unique to the challenge-seeking behaviour. Nonetheless, the challenge-seeking task not only measured challenge-seeking behaviour but also uncertainty-seeking behaviour. However, a paradigm that would distinguish challenge-seeking behaviour from similar concepts would have been a stronger measure.

The decision to engage in a math-related task has been used as a valid measure of challenge-seeking (Lee & Kim, 2014; Porter et al., 2020; Rege et al., 2021). Although it is a straightforward measure, as many people find maths tasks challenging, it might introduce emotional variables. Math is perceived as aversive (Lyons & Beilock, 2012) and usually disliked. Anxiety about maths is quite common in a young population (Chang & Beilock, 2016; Schaeffer et al., 2018). Due to the contribution of these emotional factors, the generalisation of findings of the current experiments to the non-math related tasks may be tricky. Although participants generally reported low to medium levels of math anxiety for each experiment (self-reported math anxiety), their overall avoidant attitude to explore harder word problems indicates their reluctance. Therefore, an additional experiment employing hard and easy memory-related stimuli (e.g., the number of foreign words memorised) would help understand if the social contagion of challenge-seeking observed in the experiments reported here could be generalised to non-math related tasks.

It is possible to speculate that expectancy formation gives rise to the social contagion of challenge-seeking. When participants observed the confederate choosing to solve difficult word problems, they might have expected that solving word problems would be enjoyable. However, Friedman and colleagues (2010) showed that an enhanced intrinsic motivation state was not activity-specific. Participants who observed an intrinsically motivated confederate doing a geometry task showed increased performance and intrinsic motivation in an anagram task (Friedman et. al., 2010). Since individuals cannot form expectations about the anagram task from hearing about the geometry task, individuals must be adopting the general motivational state of the confederate. The current research did not test whether the increased challenge-seeking tendency of the observer could be transferable to different cognitive tasks. Future research designed to address the transferability of facilitated challenge-seeking behaviours would be necessary to find an answer.

5.7. Future Research

In the reported series of experiments, possible contributions of various individual differences (such as self-concept, achievement goals and self-confidence) and environmental factors (such as confederate likeability and word problem difficulty) on the social contagion of challenge-seeking behaviour were investigated. These results open a whole new avenue for research. Future research investigating which other factors might be related to challenge-seeking behaviours, such as personality traits, and satisfaction of basic psychological needs (Deci et al., 1996; Ryan & Deci, 2020) would render an individual more or less prone to the social contagion of challenge-seeking would be complementary to the findings reported here.

5.7.1. Personality Traits

Personality traits have been shown to be contributing to differences in challenge-seeking tendencies. Particularly extraversion and openness to experience were linked to increased challenge-seeking tendencies.

Extraversion: Extraversion refers to the general tendency to be sociable, and to prefer frequent social interaction with a large number of contacts (Costa & McCrae, 1980). Fishman and colleagues (2011) reported higher amplitudes of P300 ERP component in those with high extraversion when they saw human faces. Considering that P300 ERP was commonly elicited by active task engagement (Picton, 1992), human faces have greater motivational significance to extraverts.

Besides the increased sensitivity to faces, extraversion has been linked to a greater need for stimulation. According to Eysenck's (1967) PEN theory, extraverts have a naturally low level of cortical arousal, and this leads to a relatively higher threshold for stimulation. To maintain an optimal level of arousal, extraverts are inclined to seek out external stimulation, such as social interactions, engaging in challenging activities, or seeking novel experiences. Although the neuroimaging research indicated mixed results, behavioural experiments provided support for Eysenck's claims by indicating that extraversion is linked to stimulation, dissatisfaction with repetitive tasks (Smith, 1995) and seeking jobs with cognitively challenging job demands (Sterns et al., 1983; Roczniewska & Bakker, 2016). Based on extraverts' sensitivity to social cues (Fishman et al., 2011) and the positive link between extraversion and the need for stimulation, it would be interesting to see if higher levels of extraversion would be associated with susceptibility to the social contagion of challenge-seeking behaviour.

Openness to Experience: Openness to experience refers to the extent to which an individual is intellectually curious, creative, and prefers novel and unconventional ideas and experiences (McCrae, 1987). Previous research showed that the openness to experience is associated with concepts similar to challenge-seeking behaviour, such as risking potential failure to try out a new way to improve work quality (Dewett, 2007) or the adoption of functional learning styles that facilitate academic success such as critical evaluation and in-depth analysis (Farsides & Woodfield, 2003). Based on the existing research, greater challenge-seeking tendency can be predicted from those who are high in the openness to experience trait. Future research investigating whether the openness to experience trait could have a contribution to individuals' susceptibility to the social contagion of challenge-seeking would be informative.

5.7.2. Satisfaction of Basic Psychological Needs

Basic need satisfaction has been linked to positive educational outcomes (Deci et al., 1996), and enhanced personal growth and daily wellbeing (Sheldon et al., 1996). Frustration of these needs predicted anxiety in school and maladaptive coping strategies with failures (Ryan & Connell, 1989). Among the basic psychological needs discussed in the previous literature (Deci et al., 1996), the need for autonomy (Ryan & Connell, 1989), the need for competence (White, 1959) and the need for achievement (Murray, 1938) fit the scope of challenge-seeking behaviour.

The need for autonomy is associated with the degree to which an individual seeks challenges. Provision of autonomy-supportive task instructions (Baten et al., 2020) or granting participants self-control over task difficulty (Pathania et al., 2019) was linked to enhanced likelihood to seek challenges in the future. The effect of the need for autonomy satisfaction/frustration on one's susceptibility to the social contagion of challenge-seeking may be an interesting research avenue for future studies.

The enhanced challenge-seeking tendencies of those with a greater need for competence or greater need for achievement have been demonstrated repeatedly (Olafsen & Halvari, 2017; Olafsen & Frølund, 2018; Mabbe et al., 2018) and they are discussed in detail in the Introduction chapter. However, these studies have not investigated the role of satisfaction and frustration of the need for competence and the need for achievement in the context of social contagion of challenge-seeking.

5.8. Take Home Message

Math-related activities are usually disliked and avoided as they require a great amount of cognitive effort. This thesis proposes a way to change the negative attitude held towards challenging activities. Watching others' willingness to engage in math-related activities can motivate the observers to do the same, especially for those with mastery-approach achievement goals. This social contagion of challenge-seeking behaviour may be linked to the enhanced frontoparietal activity observed while participants selected word problems under the influence of the challenge-seeker confederate. The experiments reported here would hopefully provide the groundwork for future research that would unravel the influence of various social factors on challenge-seeking behaviour, and lead to the design of interventions which evoke positive feelings about challenge-seeking in schools and workplaces.

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Appendix A

Example word problems presented in Experiment 1 and Experiment 2

In this experiment, you will solve 5 word problems

Each problem will be in multiple-choice format.

Please select an option using the mouse cursor.

You will have **1 minute** to solve per word problem.

You leave the house with 5 apples in your bag. When you arrive at school you realize a big hole in the bag and you count only 2 apples. How many apples must have dropped out the bag on your way to school?

▢ 2 ▢ 3 ▢ 4 ▢ 5 ▢ I don't know

Some example word problems and their accuracy rates:

You leave the house with 5 apples in your bag. When you arrive at school you realize a big hole in the bag and you count only 2 apples. How many apples must have dropped out the bag on your way to school?

▢ 2
▢ 3
▢ 4
▢ 5
▢ I do not know

95%

There is a grocery shop in the town and it is famous for its fresh apples. The shop sells the apples at £1 each. But they have a special deal at the shop. Each of these apples are wrapped in a special wrapper and you can trade 3 of these wrappers for 1 apple. Suppose that you have £15, how many apples can you get altogether?

▢ 15
▢ 21
▢ 22
▢ 25
▢ I do not know

50%

Suppose you tie a rope tightly around the Earth's equator. Then you add an extra 3 feet to the rope's length. All around the Earth the rope is raised up uniformly as high as possible to make it tight again. Approximately how high is the rope from the ground?

▢ 4 inches
▢ 6 inches
▢ 8 inches
▢ 10 inches
▢ I do not know

5%

Appendix B

Pearson correlation results investigating the correlation between participant demographics, math anxiety and math self-concept scores, and the shift in challenge-seeking rate across observation conditions.

Observation condition	Variable	*r*	*t*	*df*	*p*
Experiment 1					
Baseline – Seeker	Math self-concept	-.16	0.93	33	.361
	Math anxiety	.19	1.12	33	.272
	Age	-.04	0.25	33	.805
	Gender	.15	0.85	32	.404
Baseline – Avoider	Math self-concept	.27	1.63	33	.112
	Math anxiety	.01	0.03	33	.974
	Age	.10	0.60	33	.556
	Gender	.09	0.51	32	.613
Seeker – Avoider	Math self-concept	.01	0.03	33	.975
	Math anxiety	-.03	0.19	33	.852
	Age	.04	0.26	33	.800
	Gender	-.03	0.15	32	.881
Experiment 2					
Baseline – Seeker	Math self-concept	.18	1.32	50	.192
	Math anxiety	-.26	1.87	50	.068
	Age	-.09	0.63	50	.530
	Gender	-.01	0.10	50	.920
Baseline - Avoider	Math self-concept	-.08	0.56	50	.578
	Math anxiety	.07	0.52	50	.609
	Age	-.09	0.63	50	.533
	Gender	-.13	0.94	50	.354
Seeker – Avoider	Math self-concept	.11	0.80	50	.430
	Math anxiety	-.20	1.46	50	.152

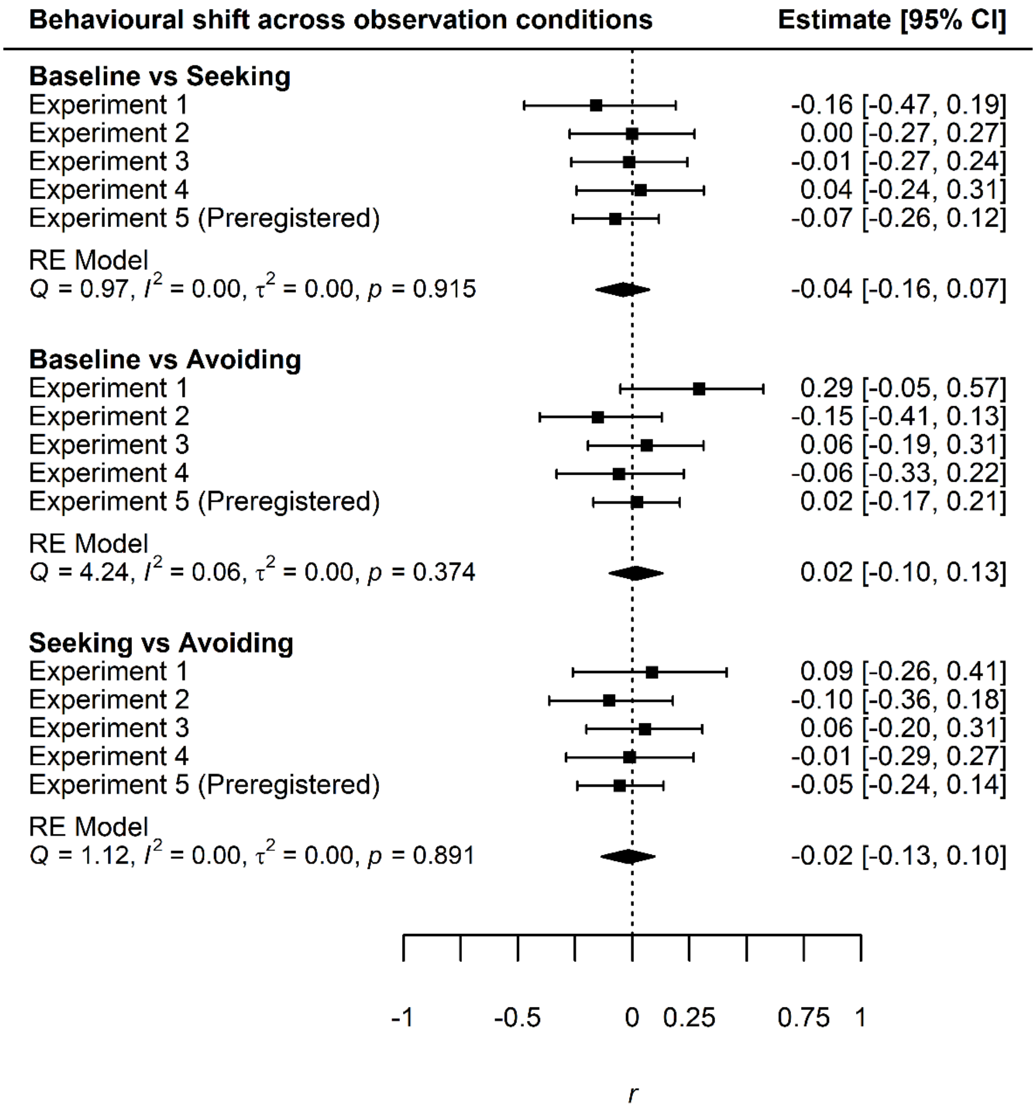
	Age	-.18	1.28	50	.208
	Gender	-.09	0.65	50	.518
Experiment 3					
Baseline - Seeker	Math self-concept	-.09	0.67	60	.507
	Math anxiety	.10	0.78	60	.437
	Age	-.05	0.36	60	.724
	Gender	-.20	1.52	58	.134
Baseline - Avoider	Math self-concept	-.01	0.11	60	.917
	Math anxiety	.15	1.15	60	.254
	Age	-.02	0.17	60	.868
	Gender	-.11	0.82	58	.416
Seeker- Avoider	Math self-concept	.09	0.67	60	.504
	Math anxiety	.10	0.78	60	.438
	Age	.01	0.08	60	.939
	Gender	-.11	-0.83	58	.408
Experiment 4					
Baseline - Seeker	Math anxiety	.06	0.39	48	.701
	Age	.09	0.60	48	.552
	Gender	.34	2.47	48	.017*
Baseline – Avoider	Math anxiety	.02	0.12	48	.903
	Age	.17	1.16	48	.252
	Gender	.05	0.34	48	.738
Seeker- Avoider	Math anxiety	.01	0.07	48	.947
	Age	.03	0.19	48	.848
	Gender	.31	2.23	48	.030*
Experiment 5					
Baseline - Seeker	Math anxiety	.07	0.73	110	.470
	Age	-.18	1.90	110	.060
	Gender	.01	0.10	107	.919

Baseline - Avoider	Math anxiety	.00	0.05	110	.964
	Age	-.06	0.62	110	.534
	Gender	.03	0.32	107	.751
Seeking – Avoider	Math anxiety	.05	0.49	110	.627
	Age	-.13	1.40	110	.165
	Gender	.03	0.26	107	.796
Likeability Experiment					
Baseline - Seeker	Math anxiety	-0.14	1.16	68	.250
	Age	-0.04	0.36	67	.719
fMRI Experiment					
Baseline - Seeker	Math anxiety	0.01	0.03	22	.989
	Age	-0.12	0.58	22	.565
	Gender	-0.12	0.54	22	.592
Baseline - Avoider	Math anxiety	0.12	0.56	22	.583
	Age	-0.11	0.51	22	.618
	Gender	-0.02	0.09	22	.927
Seeking – Avoider	Math anxiety	0.14	0.65	22	.523
	Age	-0.09	0.42	22	.678
	Gender	-0.20	0.96	22	.348

Note. Gender variable had 2 levels (male and female). For the correlation analysis, females were coded as 0 and males were coded as 1. "*" is used to emphasise the *p* values smaller than 0.05. Note that all participants in the likeability experiment were female and there were only two observation conditions (baseline and challenge-seeker conditions) for this experiment.

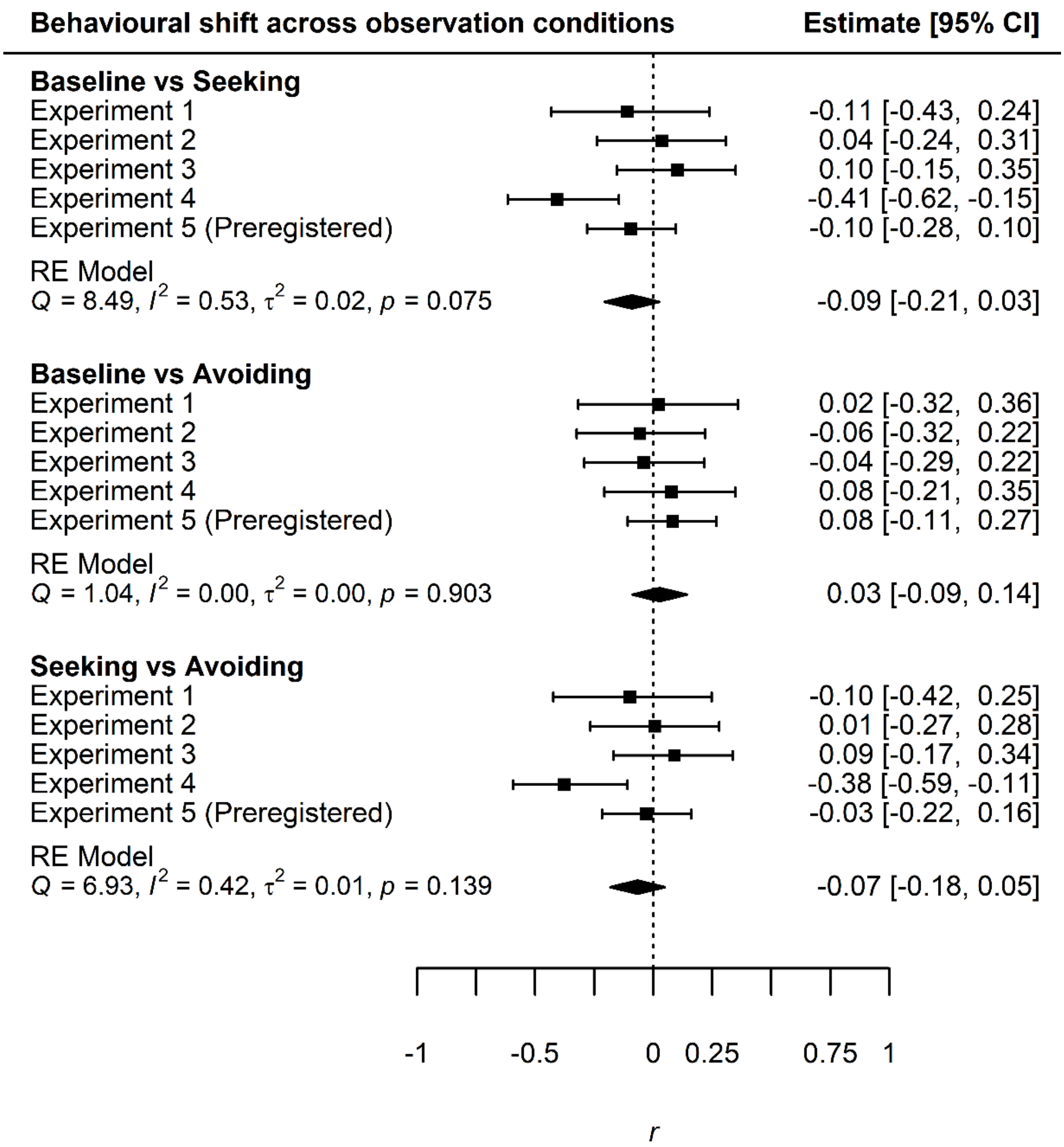
Appendix C

C.1. Forest plot showing meta-analysis across correlation between age and the shift in challenge-seeking rate across observation conditions



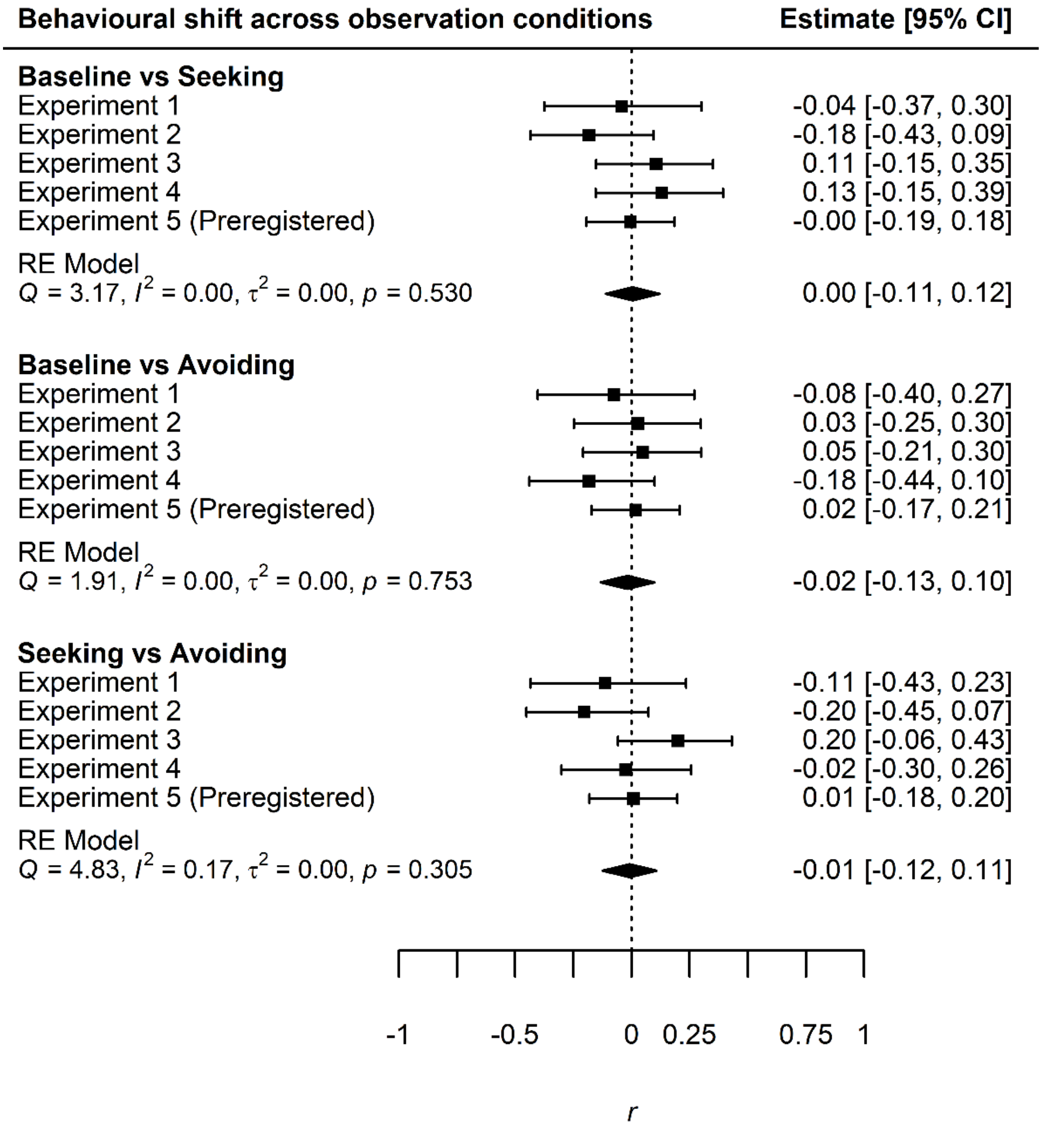
Note. Estimate is the Pearson correlation coefficient.

C.2. Forest plot showing meta-analysis across correlation between gender and the shift in challenge-seeking rate across observation conditions



Note. Estimate is the Pearson correlation coefficient.

C.3. Forest plot showing meta-analysis across correlation between math anxiety and the shift in challenge-seeking rate across observation conditions.



Note. Estimate is the Pearson correlation coefficient.

Appendix D

Experiment setup as used in the Likeability Experiment.

Note. During Phase 1, participants sat on the chairs placed by the doors of the rooms assigned to them. This setup allowed them to communicate with the confederate (part of the likeability manipulation). During Phase 2 and 3, the participant and the confederate moved inside their respective rooms but the doors stayed open during task instructions (for the Ultimatum Game and the challenge-seeking task).

Appendices E

E.1. Achievement Goal Questionnaire used in Experiment 3 was adapted from Elliot & McGregor (2001)

Please indicate the extent to which you think each of the following statements is true of you

1	2	3	4	5	6	7
Not at all true of me						Very true of me

Mastery-approach items

- I want to learn as much as possible from the upcoming word problem solving task.
- It is important for me to understand the solutions of the word problems as thoroughly as possible.
- I desire to completely master the material presented in the upcoming word problem solving task.

Mastery-avoidance items

- I worry that I may not learn all that I possibly could from the upcoming word problem solving task.
- Sometimes I'm afraid that I may not understand the solutions to the word problems as thoroughly as I'd like.
- I am often concerned that I may not learn all that there is to learn from the upcoming word problem solving task.

Performance-approach items

- It is important for me to do better than others.
- It is important for me to do well compared to others in the upcoming word problem solving task.
- My goal in the upcoming word problem solving task is to give more correct answers than most of the others.

Performance-avoidance items

- My goal in the upcoming word problem solving task is to avoid performing poorly.
- My fear of performing poorly in the upcoming word problem solving task is often what motivates me.
- I just want to avoid doing poorly in the upcoming word problem solving task.

E.2. Trait Motivation Questionnaire used in Experiment 3 was adapted from Guay and colleagues (2003)

Please indicate to what extent each of the following statements corresponds generally to the reasons why you do different things.

1	2	3	4	5	6	7
does not correspond						corresponds completely

In general, I do things...

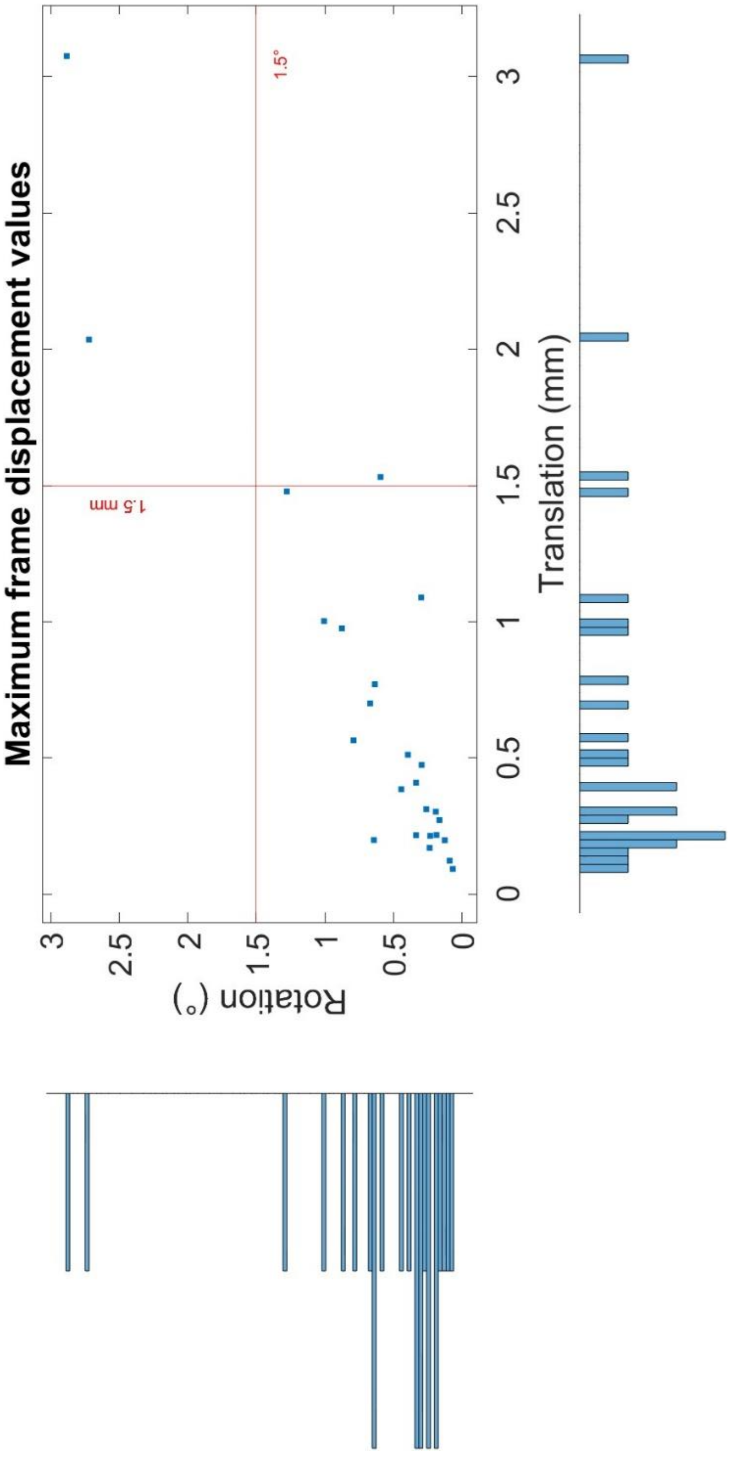
knowledge items
...for the pleasure of learning new, interesting things.
...for the pleasure of learning different interesting facts.
...for the pleasure of acquiring new knowledge.
...because I like making interesting discoveries.

stimulation items
...for the enjoyable feelings I experience.
...for the pleasant sensations I feel while I am doing them.
...because of the sense of well-being I feel while I am doing them.
...in order to feel pleasant emotions.

accomplishment items
...because of the satisfaction I feel in trying to excel in what I do.
...for the pleasure I feel mastering what I am doing.
...because of the pleasure I feel outdoing myself.
...because of the pleasure I feel as I become more and more skilled.

Appendix F

Maximum frame displacement values showing participants with excessive head motion during scanning.



Note. Five participants with excessive head motion were eliminated if their maximum frame displacement values were greater than voxel size.