ILLUSION OF CONTROL INFLUENCES STIMULUS-RESPONSE COMPATIBILITY

STACKING THE ODDS: ILLUSION OF CONTROL INFLUENCES STIMULUS-RESPONSE COMPATIBILITY IN A DISCRETE MOTOR TASK

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Abstract

The Illusion of Control (Langer, 1975) refers to individuals' misperceptions of control in chance situations. Little, however, is known regarding how illusions of control influence motor control and action planning. The purpose of this experiment was to examine the strength of the illusory control effect and, whether the strength of this effect influenced the degree to which traditional stimulus-response (S-R) associations were learned. Participants were required to make a series of virtual dice rolls by pressing on a force transducer. Participants were randomly assigned to one of three groups: congruent, incongruent, and control. Groups differed on the basis of the S-R pairs presented. The congruent group was presented with hypothetically congruous S-R pairs (high force generation = high dice outcomes and vice versa) whereas the incongruent group was presented with the reversed S-R pairs. The control group was presented with arbitrary dice outcomes, independent of force generation. The primary measures of interest were Peak Force and Impulse. When individuals were presented with incongruous S-R pairings, or random dice outcomes, no differences were found in the maximum force exerted, regardless of the outcome requested (e.g. high or low). However, when congruous S-R pairs were presented, force generation was found to be higher when a high number was requested, while the opposite was observed when a low outcome was assigned. Results suggest that participants may use outcome dependent strategies when generating virtual dice rolls.

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Introduction

The "Illusion of Control" (see Presson & Benassi, 1996 for a review) in part describes the belief that humans can influence outcomes over which they patently have no control. To date, investigations exploring this issue have largely ignored the underlying influences of motor planning and movement control mechanisms on these behaviours, focusing instead almost exclusively in casting Control Illusions in the frameworks of Social Psychology, Social Behaviour and Personality. In so doing, a vast literature related to both theoretical and applied aspects of motor control and action planning as a mediator of these behaviours has been disregarded.

Recently, Lyons and colleagues (2007) addressed these issues by posing the following motor task specific questions: Are the force parameters subserving a roll of the dice mediated by the desired outcome of the roll and, if so, is this attempt at preferential biasing evident in the observation of specific kinetic markers? Results from this study revealed that force generation varied according to the reward/penalty structures for specific outcomes. Specifically, when it was advantageous to generate a high numerical outcome, participants initiated dice rolls with a significantly higher peak force compared to when a low number outcome was requested. These results suggest that the desire to induce specific outcomes through action, when the motivation to achieve those outcomes is high, is inherent to the perception of specific events. While an intriguing conclusion, many questions remain. For example, if these illusory motor control effects are simply a transient artefact of a novel and/or artificial experimental arrangement, they may be expected to dissipate with experience. In other words, it is possible that long term repeated exposure to a true randomness of outcomes would result in a disappearance of these behaviours. One way to test this question is to manipulate the response outcome probability by creating two competing probability conditions: 1) Where trial initiation triggers of high force do in fact result in a higher proportion of high numbers and vice versa, and 2) the reverse of this conceptually congruent arrangement (i.e., high force input results in a higher probability of low numbers and vice versa). The hypothesis is clear: If the illusory control effect is simply learned, the motor outputs generated to initiate the trials will follow typical results of stimulus-response reinforcement studies (i.e., participants will quickly learn to associate kinetic output with outcome). If, on the other hand, the effect originates at a much lower level (i.e., in the CNS), a much longer learning period in the incongruent (high force = low numbers, low force = high numbers) conditions would be expected. In other words, it could be predicted that the strength of the inherent compatibility between output and outcome would significantly mediate how quickly participants adapted force production to event outcome. In fact, it could be further expected that if low force motor outputs resulted in a significantly higher occurrence of large numbers, participants would actually programme *less* force across successive trials in an effort to bring the output/outcome relationship back under control. Thus, the study comprising this thesis was designed to specifically address these issues in light of recent theories of motor control, movement preparation, stimulus compatibility, and response-produced feedback.

The Nature of Control

The notion that humans desire and strive for control over their environment has been well established among psychological theorists (e.g., Adler, 1930; Atkinson, 1957; White, 1959; de Charms, 1968; Kelley, 1971). Adler (1930) suggested that individuals are intrinsically motivated to demonstrate proficiency and superiority over events. A theory regarding an inherent motivation for control was proposed by White (1959) who suggested that individuals are rewarded with a sense of competence when they interact with events in an environment over which they believe they have control. Kelley (1971) argued that individuals seek control by way of causal analysis and attributing causation to controllable sources, specifically to events over which they desire the greatest amount of control. This desire for control, however, can sometimes result in the "illusion" that we can overtly influence environmental events that are inherently uncontrollable. Although this may sound problematic, an illusory perception of control has been argued to play an important role in individuals' lives in that it often provides a sense of satisfaction and optimism, while diminishing the destructiveness of impending situations (Lefcourt, 1973). Through the establishment of causal relationships and contingencies between response and outcome, individuals can discredit chance, which ultimately eliminates anxiety that events are uncontrollable. The importance of illusory control becomes increasingly more apparent in situations where there is an absence of perceived control. Glass and Singer (1972), for example, found individuals who perceived a lack of control had greater performance decrements and increased frustration. Seligman and Maier (1967) used the term "learned helplessness" to describe situations where individuals believe that their actions are independent of the outcome. Research in this area has demonstrated the negative effects associated with exposure to uncontrollable events. Seligman (1975) described learned helplessness as being closely related to depression; individuals exposed to uncontrollable events were characterized by passivity, anxiety and stress. Individuals who experienced situations of helplessness were slow to initiate responses, under the assumption it would be ineffective in producing change. These negative effects however, were not observed in identical situations where individuals perceived a sense of control (see also Hiroto & Seligman, 1975; Miller & Seligman, 1975). The research regarding the nature of control would suggest that there is a value associated with control and, not only are humans driven to control their environment, the mere perception of control is advantageous in interacting with this environment.

Illusions of Control

The desire for control does not seem entirely unreasonable when considering that humans are most experienced in situations where they are very much in control over the outcome. In the case of goal-directed movements, the outcome is usually a direct result of the movement production strategies employed by the individual. Consequently, the individual can formulate a causal link between their actions and the outcome, with the outcome being attributed to the preceding actions. In some cases, however, conditions arise that are wholly uncontrollable and the outcome is often arbitrary (i.e., chance events). Despite these factors being beyond the actor's overt control, these latter situations are frequently and incorrectly attributed to individual skill, resulting in illusory perceptions of control.

An Illusion of Control theory was developed by Langer (1975) who used games of chance (i.e., card games, lotteries, etc.) to illustrate this phenomenon. Langer described the illusion of control as "an expectancy of a personal success probability inappropriately higher than the objective probability would warrant" (Langer, 1975, p. 313). In a series of six experiments Langer demonstrated that illusions of control arise when factors or behaviours associated with skill are present in situations where the outcome is entirely attributed to chance. These skill related factors were identified as competition, choice, stimulus or response familiarity (i.e., practice), and active or passive involvement (i.e., executing own response versus having response completed by another individual) (Langer, 1975). When these factors were present, participants were inappropriately confident and approached chance situations with behaviour that was suited for a skilled event.

In a subsequent study, Langer and Roth (1975) determined an additional factor, outcome sequence (the pattern of wins and losses), contributed to illusory control. The study involved manipulating the outcomes of a series of coin tosses with either an initial succession of successful outcomes or of failures. Participants attributed a successful sequence of tosses early in the task to their "skill" and consequently disregarded subsequent unsuccessful outcomes. Conversely, an initial series of unsuccessful outcomes were acknowledged as being the result of chance. The results indicate that individuals develop performance strategies early in the task on the basis of the information provided thus suggesting a desire to make an association between response and outcome. These findings supported a prevalent theme in literature proposing that individuals attribute successful outcomes to internal factors (e.g., skill) which are controllable and accredit negative outcomes to uncontrollable external factors, specifically luck or chance (see Presson & Benassi, 1996 for a review).

The Illusion of Control versus the Illusion of Prediction

In a meta-analysis of fifty-three experiments pertaining to the illusion of control, Presson and Benassi (1996) found a positive and consistent illusory perception of control across the literature. Indeed, this illusion of control can be generalized across several diverse situations (i.e. lotteries, draws, computer tasks), which further emphasize human desire to find response-outcome contingencies. In addition, Presson and Benassi observed that the literature concerning the illusion of control lacked a standard application of the term. Many studies, including the basis for the theory developed by Langer (1975), examined abilities to predict the outcome rather than measures of direct personal influence over the outcome. For example, Illusions of Control were measured according to the amount wagered during a task, the participants' level of confidence and the participant's willingness to trade tickets or accept computer generated lottery numbers (Presson & Benassi, 1996). Main criticisms of these earlier studies included a lack of direct quantitative measures of control in the analyses, which were mainly concerned with qualitative indirect measures of perceived prediction ability. Interestingly, at the time of the review, none of the illusory control literature had been published in motor behaviour literature.

In all of this literature, Illusory control was assessed on the basis of gambling behaviour however, there were no quantitative measures to examine whether there were differences in movement strategies for individuals experiencing illusory perceptions of control. In some studies, individuals never won any money at the end of the task, therefore the motivation to see a particular outcome may have differed from a participant who had a greater desire to obtain a particular outcome on account of the end reward. In these cases, a differing amount of motivation could have a large impact on the level of illusory control.

Psychological Motive behind Control

There may be a variety of factors that drive the human desire for control; reasons that vary across individuals that could be based on personal experiences or the value individuals attach to observing a particular outcome. Langer (1977) suggested a psychological basis for this erroneous assessment of control, proposing that individuals have a diminished ability to discriminate between skill and chance on account of their close association in human experiences. In many situations, there is the possibility for elements of both skill and chance to be present. Consequently, the inability to determine the true nature of a situation results in illusory perceptions of control.

Several psychological and sociological researchers have attempted to explain the reasoning behind illusory control. It was hypothesized that personality characteristics were responsible for susceptibility to illusions of control (Burger & Cooper, 1979). Subsequently, Burger and Cooper (1979) developed the Desirability of Control (DC) Scale, which was designed to measure individual differences in the general desire for control. The motive to control was found to interact with situational variables; in situations where "control" cues were more apparent (e.g., participant able to place bet before dice roll) the individuals who scored high on the DC scale, wagered significantly higher bets compared to the other participants. Similar results were found using a card game and coin-toss task with an association found between participants' familiarity with the task or task outcome sequence and their score on the DC scale (Burger, 1986). In an earlier study, Burger and Schnerring (1982) found the relationship between desirability of control and illusions of control was present only when there were extrinsic incentives associated with the task (e.g. participants could trade earnings for a prize). The authors demonstrated that the illusion of control was absent when there were no incentives associated with the task.

These results however, are not consistent with other studies in the literature. For example, no relationship was found between the illusion of control effect and the desirability for control in a dice-betting task (Wolfgang, Zenker, & Viscusi, 1984) or in a computer task, which involved determining the relationship between letter-digit combinations and keyboard responses (Rudski, 2000). Despite the discrepancy in the literature regarding the susceptibility to illusory control, it would appear that motivation is a necessary factor. Wortman (1975) highlighted the importance of motivation in a marble selection task. Participants, who were aware of the marbles' prize value prior to the task, and actively selected the marble, perceived more control over the outcome, more choice and more responsibility when compared to participants who had no prior knowledge of the prize values. This would suggest that individual differences in illusions of control are related to an individual's level of motivation to observe a particular outcome. The importance, in this case the prize value, or the amount of money won, would vary between individuals depending on how much value they place on the outcome, and their level of motivation in attaining the outcome. If motivation was not sufficient during the task, it may not be considered a "risk" as individuals may not feel a threat of losing anything. As a result, they may become more aware of the chance related cues, the lack of contingency between response and outcome, and consequently, not display illusory control behaviour.

Others have suggested that illusions of control can be attributed to decision making processes based on heuristics (e.g., Tversky & Kahneman, 1974; Thompson, Armstrong, & Thomas, 1998). Heuristics are problem-solving strategies that reduce the number of operations involved in arriving at a solution. The application of heuristics in a given situation allows for faster information processing and a quick determination of causation. Once employed however, heuristics are difficult to change and potentially interfere with the identification of actual and existing causal relationships (Tversky & Kahneman, 1974). Heuristics were further demonstrated by Rudski (2000) using a key pressing task. Participants were required to determine what key was responsible for awarding points on a computer paired with a tone presented at three different delay periods. It was shown that as the latency between instrumental response and reinforcement increased, individuals began to exhibit more stereotyped patterns of behaviour, with greater importance placed on nonessential responses. Although key "6" was the correct response, when the latency increased, participants placed more importance on the other keys, with the number of key presses increasing as the latency increased. In order to further test illusory perceptions of control as per Langer (1975), participants were asked whether they would trade self-selected lottery tickets for computer generated tickets. Participants who responded no were more likely to include non-instrumental key responses in their pattern of key presses compared to participants who were willing to trade their ticket. When the delay between response and outcome increased, participants' ability to detect causality decreased. Rudski attributed these nonessential responses to a reliance on what he referred to as contiguity-causality heuristics. Individuals would apply this form of heuristics to situations in an attempt to make contingencies between stimulus and response in order to apply causality to the outcome.

Thompson, Armstrong, & Thomas (1998) suggest that people rely on heuristics when assessing control, specifically that illusions of control are positively related to the need for the outcome (i.e., the value or importance of the outcome), and that these illusions increase when conditions emphasize attention to desired outcomes. Consequently, this leads to overestimation in the occurrence of the presumed factor responsible for the outcome and the number of times that it coincides with the actor's behaviour. In this case, the behaviour displayed during these illusions of control would not seem irrational, suggesting that when points or poker chips are awarded, attention to desired outcomes would increase as would the perception that these outcomes are the result of an individuals own skill. Thompson et al. (1998) suggested that people rely on "control" heuristics, the subjective judgement that an action is responsible for a specific outcome, when assessing control. This results from the number of times an action is followed by a desired outcome, an association that is made between two elements, or a predictive connection based on the relationship between prior expectations and outcomes. This is in line with that of Langer and Roth (1975), which suggests illusions of control are influenced by the probability of a desired outcome. When the frequency of desired outcome was greater, people perceived it to be the result of their own control.

Although the above examples speak toward the existence of a "general" illusory control effect, a corollary line of evidence exists to suggest that this desire to control the uncontrollable extends to motor behaviours and actions.

Ideomotor Action

There is a notion in psychology which asserts that merely the thought of an intended action effect is sufficient to automatically trigger the desired movement. This concept can be illustrated in situations where an individual has initial control over an action up to a given point, after which time they relinquish this control. Bowling, for example, is a game in which the individual initially has control over the entire production of the movement (e.g., force, direction, etc.). Consequently, if the bowler's original motor plan contains any errors, online corrections can not be employed to resolve them. Despite this lack of overt control, the individual will often display body movements that suggest an attempt to maintain control. Typically, these behaviours include things like head and body movements in the direction of the intended course as the ball travels in the opposite direction. This phenomenon was introduced to the literature by British scholar William B. Carpenter (1874), which he referred to as ideomotor action. Carpenter used the term ideomotor action to describe actions that are guided by ideas, movements that are relatively automatic in nature and often occur without or even counter to voluntary control. In support of his theory, Carpenter presented the swinging pendulum phenomenon wherein a pendulum, which the participant was instructed to keep still, was suspended from an individual's forefinger. Slowly however, the pendulum began to swing. It was suggested that the idea of the pendulum, and its function, induced unintentional or counter-voluntary movements of the forefinger.

Lotze (1852) developed a theory of voluntary action which suggested the existence of a causal relationship between thoughts and action. The basis of this theory was a learning process that occurred between the body and soul, where the body teaches the soul, via the sensory consequences of movement, how to purposefully use the body. This relationship was also described to exist in the reverse direction in order to initiate movements (see Stock and Stock, 2004 for a review). Through an integration of both the theoretical ideas of Carpenter (1874) and Lotze (1852), William James (1890) more narrowly defined ideomotor action to denote involuntary muscle activity driven by a dominant idea, specifically the movement effects in the mind. James further expanded his definition of ideomotor action to include the movements performed by an individual that correspond to movements that are simply observed.

In a historical review of ideomotor action, Stock and Stock (2004) summarized ideomotor actions as movements that are initiated by the anticipation of action effects. Specifically, the actor must have previous experience with the actions from which they learned about the specific effects of the movements. Despite the rationale for the concept, there was little advancement in this area during the first half of the twentieth century, ideomotor action having been denounced in psychology as "magical" thinking (Thorndike, 1913).

More recently however, this concept has received attention as being a link between action and perception. In line with previous descriptions, ideomotor action has been regarded as involuntary (or even counter-voluntary) body movements that occur while observing the outcome of one's own performance or even when watching *other* individuals perform certain actions.(Knuf, Aschersleben, & Prinz, 2001; De Maeght & Prinz, 2004). These movements are often characterized as limb movements or shifts in body weight. Action induction has also been further subdivided on the basis of perceptual interpretation as either perceptual induction or intentional induction. Perceptual induction is often likened to a form of imitation in which individuals perform the movements they observe. Conversely, intentional induction is characterized by movements the observer would like to see, or what *should* happen.

Through a series of three experiments, Knuf et al. (2001) examined action induction using a virtual billiards task. It was found that the pattern for induced movements differed across effectors (e.g., head, hands, and feet) and was dependent upon which were instrumental for task performance. In this case, strong induced hand movements were observed which were guided by the intended ball pathway. Perceptual induction was evident in non-instrumental effectors (e.g., head and feet), which were guided by the most prominent image on the stimulus display. An interesting finding to note was that action induction was only prevalent on trials resulting in misses. However, for trials in which there were potential successful target hits, there were no systematic movements. Similar results were reported by De Maeght and Prinz (2004) where a bowling task was used to further examine action induction. It was shown that induced movements differed depending on whether individuals were actively involved in movement production or were solely observers. Performers exhibit movements with a strong dissociation between instrumental and non-instrumental effectors, while observers display movements in accordance with what is being observed.

Although these results support the existence of ideomotor action, they do not address the mechanisms responsible for inducing these involuntary movements. One possibility involves the concept of Feed-Forward control. In general terms, Feed-Forward models involve the continuous evaluation of movements in accordance with the visual feed-back provided of what is being observed. Thus, the involuntary movements observed in situations of action induction could be the result of what *should* be performed if the individual continued to have control over the movement.

Internal Models of Control

This illusive perception of control can also be attributed to the fact that in the majority of situations humans encounter, the outcome is usually the direct result of their behaviour. Many goal-directed movements are the direct result of the interaction between motor commands from the central nervous system and environmental feedback. Tasks such as picking up a glass or moving from a seated to standing position are likely due to the development of the appropriate feed-forward information during movement sequence. This feed-forward information is developed through motor commands and the interpretation of feedback regarding the end result of the movement sequence. Over the last two decades, such model-based strategies have been used to explain the execution and control of human movements (Kawato, Furukawam, & Suzuki, 1987; Miall & Wolpert, 1996; Kawato, 1999). It has been suggested that the ability to make predictions regarding movement outcome can be made based on the information provided from the interaction between the internal models of the motor system and feedback from the external environment. At its most basic level, these internal models can be divided into those of forward and/or inverse models. Forward models predict the next sensory state of the motor system on the basis of the current state and the motor commands being issued. Inverse models, conversely, are concerned with the intended action and the motor commands required for its achievement. Sensory representations are inverted into motor commands and ultimately guide performance.

It has been suggested that the process by which goal-directed movements are completed is due to internal forward models (Wolpert, Ghahramani, & Jordan, 1995; Miall & Wolpert, 1996; Kawato, 1999). These forward models enable the prediction of the outcome or consequences of action, prior to the availability of sensory feedback which can minimize the effect of sensorimotor processing delays, thus increasing control. The integration of both sensory and motor signals reduces the overall uncertainty of this estimate. Input to the internal model derives from the current state (e.g., velocity and joint angles) and motor commands (efferent outflow) from the controller, producing an estimate of the new state, or the set of parameters that determine behaviour (Wolpert, 1997). In order to achieve the requisite end goal, therefore, these voluntary movements undergo continuous modifications by way of internal forward models where the current state of the effector is evaluated against the desired state, thus comparing the present situation against what it should be.

Forward models have generally been employed to explain behaviours in situations where the outcome is primarily reliant on the actions under control and the consequences of these actions. In the case of a voluntary goal directed movement, the central nervous systems (CNS) sends out the appropriate motor commands (efferent signals) from which the movement is generated. Afferent signals are then sent back in the form of sensory feedback, which allow for error correction in order for successful completion of the desired task. In such a scenario, internal models can be used to explain achievement of the desired goal. It is not clear whether internal models can account for situations where the action execution parameters do not influence the outcome, which are entirely based on chance. In this case, the outcome would not provide information regarding whether the movement production strategies were beneficial to achieving the movement goal.

Conceptual Compatibility

In certain situations, humans have been shown to be exhibit consistent responses to presented stimuli regardless of the possible response alternatives. Fitts (1951) identified this repeated performance as population stereotype, where there is uniformity in the response elicited for a stimulus that is selected based on individuals' expectations regarding the stimulus. For example, this stereotyped compatibility can be observed in interaction with a round doorknob or when tightening a bolt (where the response is to turn in a clockwise direction), or when using a light switch (where pressing up is associated with "on" and down with "off"). Similarly with a joystick, a forward motion would be expected to induce forward movement of the stimulus, and the reverse motion to move backwards. Small (1977) described this compatibility as the state of congruence between the presented stimulus, which he refers to as environmental inputs, and the resultant response. The primary objective is to establish effective matches between stimulus and response.

The impact of stimulus-response congruence has been examined in perceptual-motor tasks. The Stimulus-Response (S-R) Compatibility effect suggests that performance is dependent on S-R pairings. The most efficient performance is observed when the response is appropriately matched to the stimulus source and therefore, the amount of information transferred during the task is at a minimum (see Fitts & Seeger, 1953; Fitts & Deininger, 1954). Although S-R compatibility and population stereotypes are both associated with the congruence between stimulus and response, S-R compatibility refers to the speed and accuracy with which a response is elicited. Population stereotypes alternatively, are concerned with the response that is most frequently selected specifically, the response preference (Yu & Chan, 2004). Nevertheless, both processes provide insight regarding human behaviour that is beneficial for optimizing performance.

The term compatibility is in itself quite general, encompassing the four possible domains: conceptual, movement, spatial and modality compatibility (Sanders & McCormick, 1992). Although all have some degree of influence on movement, perhaps the most robust of these compatibilities is spatial. In a seminal study exploring this effect, Fitts and Seeger (1953) examined the effect of spatial compatibility and movement direction on performance. It was found that the speed and accuracy of responses corresponded with the compatibility between the light array and response sequence presented. For example, when the stimulus response pair was "incompatible", such as a circular light array paired with a linear control switch, responses were slower and less accurate compared to when a "compatible" stimulus response pair (e.g., circular light array paired with circular response set) was presented. Fitts and Seeger (1953) suggested that the rate at which the perceptual motor system processes information is related to the amount of congruency between stimulus and response. In situations where the spatial compatibility was greatest, information processing was faster and ultimately, more accurate. Kornblum, Hasbroucq, and Osman (1990) proposed a cognitive model to describe the effectiveness of compatible S-R ensembles. Congruent S-R pairs were suggested to share commonalities between them, which leads to an automatic activation of the response program combined with the activation of a response confirmation program that verifies whether response meets the requirements of task instruction. When there is incongruence between stimulus and response, additional processing is required in order to terminate the automatic response and to initiate one that is task appropriate. When there is S-R compatibility, the response is executed rapidly and correctly however, if stimulus and response are incongruent, the response will be executed at a slower rate and with less accuracy.

Smith (1981) investigated population stereotypes using a questionnaire covering all four domains of compatibility. The questionnaire was distributed to a group of male engineers, a diverse group of women, and human factor specialists. The questionnaire responses revealed population stereotypes for unambiguous scenarios (e.g., direction of knob turning, direction of key teeth when key in a lock) however, in situations where responses were influenced by individual experience, there was diversity among groups in their responses. Expanding from these results, Yu and Chan (2004) explored cross cultural population stereotypes comparing the responses regarding common perceptual motor skills of Mainland Chinese students with that of Hong Kong Chinese (see Courtney & Chan, 1998) and Americans (Smith, 1981). Once again, strong stereotypes were found for specific tasks (i.e., knob turning, door handles) however, differences in stereotype strength were observed across the three cultural groups, with more similar stereotypes observed between Mainland and Hong Kong Chinese possibly owing to similar cultural environments (Yu & Chan, 2004). Response selection was suggested to be influenced by personal experience and cultural associations. However, these measures of stereotyped compatibility were qualitative in nature, predominantly that of perceived compatibility, as responses were based on participants perception of how they would theoretically perform a task. The diversity in responses, typical of the more ambiguous questions, may have been the result of differences in perception when reading about a scenario versus active involvement. When an individual is actively involved in a situation, information from the environment may provide cues that would affect how individuals interact with the "stimulus" and ultimately influence response selection, information that would not be available in hypothetical situations (i.e., the characteristics of the object such as size or shape).

The existence of a spatial-numerical compatibility has also been discussed in literature with observations of a numerical distance effect (e.g., Moyer & Landauer, 1967; Dehaene, Dupoux, & Mehler, 1990). An inverse relationship between the numerical distance of two numbers and the time required to compare them has been demonstrated such that the quickest responses corresponded to greater numerical distances. For example, when the numerical distance between two numbers is large (e.g., 1 and 5) the response is executed much faster compared to when the numerical distance is smaller (e.g., 4 and 5). This spatial-numerical compatibility effect is illustrated by the Spatial-Numerical Association Response Codes, SNARC effect that demonstrates the spatial coding of numerical magnitude (Dehaene, Bossini, & Giraux, 1993). In Dehaene et al. (1993) participants made a series of parity (even-odd) judgements on presentations of Arabic numerals. It was found that numbers were conceptualized on a "mental number line", with numbers arranged in ascending order from the left to right side of space. Interestingly, individuals responded faster to parity judgements when smaller magnitude numbers (0-4) were on the left side of space and larger numbers (6-9) on the right. The numbers presented were spatially classified according to magnitude despite it being irrelevant to the parity task. It was suggested that presentation of Arabic numerals results in the automatic activation of its corresponding magnitude code. This raises the question as to whether compatibility effects associated with numerical magnitude are restricted to the spatial domain, or whether these compatibility effects influence action execution parameters of voluntary movements.

The association between intensity of sensory stimuli and strength of corresponding response were examined using diverse light intensities and button press forces by Romaiguère, Hasbroucq, Possamaï and Seal (1993). Participants were seated in front of a column of light emitting diodes (LED) and were required to hold a manipulandum, which rested their right thumb on a force sensor. Following an auditory cue, participants made either a weak or strong press on the force sensor according to the light intensity with which they were presented. Demonstrating a stimulus intensity and force S-R compatibility effect, faster reaction times were exhibited by the congruent group, who experienced an S-R compatible situation which paired a strong stimulus (bright light) with a strong press response and a weak stimulus (dim light) with a weak press compared to the incongruent group, who were presented with the reverse S-R mappings. The authors proposed the stimulus intensity – force compatibility effect was the result of a symbolic translation, where the S-R compatibility is a learned association (e.g., combining large/small with strong/weak, strong/weak with bright/dim). If compatibility between stimulus intensity and response force is a learned association, and Arabic numerals are coded according to their magnitude (e.g., Dehaene et al., 1993), it could be hypothesized that this compatibility effect would appear between numerical magnitude and other movement parameters. Walsh (2003) proposed a Theory of Magnitude (ATOM) to explain the relationship between cognitive representations of numerical information and movement parameters. Walsh hypothesized a shared generalized magnitude system between time, space, and quantity, with a link between the processing of symbolic and quantitative information and the motor system. This would suggest that the properties of the stimulus presented, whether numerical, spatial, or temporal, would influence the movement parameters of the response.

Recently, some empirical evidence has emerged providing support for an association between numerical processing and goal directed actions, in particular between numerical magnitude and hand responses. For example, Andres, Davare, Pesenti, Olivier, and Seron (2004) found an interaction between numerical magnitude of Arabic numbers and grip aperture of the thumb and index finger. Participants were presented with numbers ranging from 0-9 to which they made parity judgements responding with instructed grip position (either open or closed). The results indicated a faster grip closure for smaller digits, while grip opening was initiated faster when large digits were presented. The movements of the fingers, however, were only imitations of grasping movements, as participants were not required to grasp a physical object during the study. A similar S-R paradigm was used by Lindemann, Abolafia, Girardi, and Bekkering (2007) with the addition of a wooden cylinder to facilitate real grasping movements. Participants made memory guided reaching movements to a wooden cylinder consisting of a large base and smaller cylindrical top portion, which facilitated either a power grip (associated with large items) or precision grip (coupled with small items). Participants were instructed to grasp either the base or smaller portion of the cylinder according to the parity of number presented. Precision grips were found to be initiated faster in the presence of small digits (1-2) while power grips were performed more rapidly when large numbers (8-9) were presented.

More recently, Moretto and di Pellegrino (2008) further demonstrated the interaction between number magnitude and action processing specifically with isolated grip movements using two different S-R protocols. In the first paradigm, participants performed hand grasping movements, either precision or power grip, according to the parity of Arabic numerals presented. In the second experiment, grip selection was based on the colour of the number presented. In both conditions the speed and accuracy of hand grip responses were associated with number magnitude; small magnitude numbers eliciting faster precision grip responses and larger numbers paired with the power grip. These movement patterns were observed even when number was irrelevant to the task (i.e., colour condition). The automatic activation of number quantity is also in line with previous studies concerned with a numerical size congruity effect (Schwarz & Heinze, 1998; Schwarz & Ischebeck, 2003). Reaction times increased when there was incongruence between the physical size of a digit presented and its magnitude. The cognitive representation of quantity is automatically activated even though the numerical magnitude is irrelevant to the task. Although support for an interaction between numerical processing and movement parameters has been demonstrated, the literature was primarily concerned with kinematic measures (i.e., reaction time) and error rates of movements. An interesting question is whether or not magnitude would influence kinetic parameters of action execution (e.g., force). If S-R compatibilities can be the result of learned associations as suggested by Romaiguère et al. (1993), it could be hypothesized that similar S-R compatibilities would be displayed with kinetic measures of movement production, such as greater force production with high magnitude digits and lesser force associated small magnitudes. It is not clear however, whether the compatibility effects between numerical information and action parameters is present only with Arabic numerals, where the semantic meaning is obvious, or whether it would be present with diverse presentations of numerical information (i.e., dice).

Numerical Magnitude, Action Execution, and Games of Chance

Numbers play a significant role in many aspects of human life. Numerical information is presented in many different forms; as a digit, in written and verbal communication, and even in abstract forms (e.g., markings on a die). There are specific meanings and associations that individuals attach to numerical presentations as numbers provide information such as the time of day, the size and weight of an object, the age of a person, and even the "value" of an item represented by its cost. Numerical stimuli form cognitive numerical representations and subsequent numerical processing according to the stimuli presented (see McCloskey & Macaruso, 1995 for a review). Given the significance attached to numbers, it is not surprising that numerical stimuli influence action execution parameters (e.g., Andres et al., 2004; Lindemann et al., 2007; Moretto and di Pellegrino, 2008). It is important to note that the previous literature required participants to perform voluntary movements in which the outcome was a direct result of the movement strategies employed. Although numerical magnitude influenced the speed and accuracy of these responses, the individual was ultimately in control of the end result; their actions were responsible for the outcome. Conversely, there are situations where the end result is independent of the movement production strategies employed. This scenario is best illustrated in games of chance including coin tosses and dice games, tasks in which, despite how the actor performs the movements, the outcome is always arbitrary. The literature surrounding games of chance and the illusion of control (Langer, 1975; Presson & Benassi, 1996) suggest individuals perceive control during chance situations evidenced by qualitative measures of behaviour. This raises the question as to whether this illusory control would be demonstrated on quantitative measures of performance (i.e., response force) in chance situations where the outcome is not a function of movement parameters. In particular, whether or not numerical stimuli (i.e., dice) would influence movement parameters during games of chance.

Many popular culture games require the use of dice. Dice have been associated with luck or chance with corresponding behavioural patterns often displayed, such as blowing on the dice or variations in the force or speed of the roll. These behavioural patterns of dice rolling were examined by Henslin (1967), who observed "magic" in games of craps. The initial hypothesis was that gambling behaviour was based on outcome probability however, after observing a series of games Henslin witnessed behaviour indicative of a game of skill. In particular, bets and rolls were made as if performers controlled the outcome of the dice roll. When a low number was desirable, players would exert control by softly tossing the dice, while a forceful toss was exhibited when a higher number was desired. Throughout the games, Henslin observed players exerting a lot of effort and concentration despite their lack of control in the outcomes. The behavioural patterns observed were described as not only being specific to the players but was also observed among the spectators. Observers would often instruct or caution movements suggestive of "irrational" thinking shared by both individuals actively involved in the game and also among bystanders. Although the behaviour was suggestive of illusory control, the findings were based upon behaviour observed by Henslin, lacking any quantitative measure of whether an actual difference in dice roll force existed according to desired numerical outcome.

Recently, Lyons, Grierson, Kegel, Cheng, and Lee (2007) developed a virtual dice rolling paradigm in which participants initiated virtual dice rolls by pressing on a force transducer that measured the force exerted on each trial. The outcomes of the dice rolls were completely random and unrelated to the force applied to generate dice rolls. Participants were either rewarded or penalized poker chips for the outcome of their dice rolls according to the payout matrices in use. It was found that the force used to initiate the trial was dependent on the assigned outcome; if a high number was requested the trial was initiated with a significantly higher peak force, while the reverse was found when a small number was assigned. A finding of particular interest was that the strength of these observed effects increased over time despite participants having observed that the force generated to initiate trials had no influence on the outcome. These illusions of control were present when the motivation to achieve a specific outcome was strong. However, the locus of this illusory effect remains unclear. One possibility is that the illusions of control displayed in the virtual dice rolling task are due to a stereotyped compatibility effect operating at a low level within the CNS and consequently, resistant to modification. An alternative hypothesis is performance parameters are a higher order effect that is adaptable and therefore, susceptible to learning. A stimulus-response learned association protocol can be employed in order to distinguish the two possible loci. The purpose of this thesis was to differentiate the two possibilities.

In force production studies, it has been shown that individuals are relatively unaware of force generation, demonstrated in force replication tasks. Shergill, Bays, Frith, and Wolpert (2003), found that participants were unable to accurately replicate the force with which they had been previously presented as demonstrated by a substantial increase in self-generated forces over the course of the study. While Shergill et al. (2003) found that individuals displayed a diminished perception of force production over time Lyons et al. (2007) in contrast, found participants were perceptive of their force generation. Specifically, individuals attempted to manipulate outcomes by way of force variations. Taking the two studies together, it could suggest that in relatively trivial situations, people are unaware of their force production. Once motivation becomes a factor in the situation, such as to win money, individuals will adjust performance parameters even though, specifically in games of chance, they will not influence the outcome.

The aim of the present study therefore, was twofold. The first aim was to investigate the robustness of the behavioural illusory control effects using a virtual dice rolling task borrowed from the paradigm developed by Lyons et al. (2007). The second aim of the study was to determine the locus of the illusory control effect by using a stimulus-response learned association protocol. Specifically, the probabilities of dice outcomes were manipulated to be contingent on the force generated to initiate each dice roll. The force-outcome contingencies helped to distinguish the possible loci because if participants displayed similar force response regardless of outcome manipulation, it would suggest a stereotyped compatibility effect owing to its resistance to modification. However, variations in force production between diverse outcome manipulated groups would imply a higher order adaptable effect that is susceptible to learning. In the present study, the dice roll outcomes were manipulated according to group; congruent, incongruent and control. For the congruent group, high force production was reinforced with the presentation of a greater percentage of high number outcomes and low force generation was associated with low number outcomes. For the incongruent group however, seemingly incompatible behaviour was reinforced, with high force generation paired with the presentation of low number outcomes while low force was paired with larger magnitude outcomes. The control group was presented with random outcomes, serving as the baseline between outcome manipulated groups.

According to this force-outcome contingent paradigm, three possible outcomes could have been observed. One possible observation was that both groups learned the association between response and outcome (stimulus-response) at equal rates. More specifically, groups learned the force response needed to generate the assigned outcome. An alternative result could have demonstrated different learning rates for each group, with the congruent group aware of the association at a faster rate than the incongruent group. It would be expected that the incongruent group would display a longer period of erroneous behaviour before discovering the force-outcome contingency. The third possible outcome, contrary to the previous two potential observations, is that participants would not learn the response-outcome association, but rather, individuals would continually attempt to influence the outcome through their behaviour. If behaviour were simply a learned effect, the force generated would be attuned early in the task as participants begin to associate a stimulus-response relationship between the force generated and the outcome of the dice roll. Accordingly, this learned behaviour could be the product of operant conditioning (see Staddon & Simmelhag, 1971 for a review). If behaviour is continually rewarded, it is expected that the frequency of this behaviour will increase. Conversely, if behaviour continually receives negative reinforcement, as would be the case for the incongruent group, it was expected that this erroneous behaviour would cease.

It was hypothesized that the present study would yield results in accordance with the third possible outcome, in which participants do not learn the association between response and outcome, but rather try to impose change on the outcome over successive trials. Contrary to operant conditioning, the behaviour observed could be driven by a desire to maintain control over the outcome, rather than being influenced by a specific reinforcement schedule. Participants may have been motivated to produce a specific response in an attempt to obtain an outcome they considered more suitable with their behaviour (e.g., increase the force of their responses overtime since that should eventually yield a high number), thereby trying to impose change on the outcome over successive trials. Participants would adjust their behaviour in a manner they believed was correct (i.e., large number paired with high force, low number paired with small number), and these adjustments made until the assigned outcome was attained. This type of behaviour seemed to be evidenced by the lack of learned adaptation in Lyons et al. (2007)

and is further investigated here. Additionally, this behaviour would be contrary to operant conditioning, as the behaviour is driven by a desire to maintain control over the outcome and therefore not influenced by a specific reinforcement schedule.

Method

Participants

Thirty-two students (14 male and 18 female; mean age 20.5 ± 2.24 years) from the McMaster University community participated in this study. Participants were assigned to one of three groups; Congruent (n=10), Incongruent (n=10), and Control (n=12). The groups differed on the basis of the stimulus-response relationship presented (see Procedure). Assignment to groups was random however gender was maintained as approximately equal between groups. Thirty of the 32 participants self-reported to be right hand dominant and all individuals possessed normal or corrected-to-normal vision. Participants were naïve to the purpose of the study and all provided written, informed consent prior to participation in accordance with the ethical guidelines of the McMaster University Research Ethics Board (MREB). Participants received either monetary compensation ($5) or one course credit for participation in the study plus any additional monies "won" during the two experimental sessions as outlined in the procedure.

Apparatus

The experimental stimuli were developed and displayed with E-Prime (v2.0) software (Psychology Software Tools, Inc., 2007). The dice combinations were presented on a computer monitor located on the top of a bench with a height of approximately 105 cm. A table measuring approximately 76 cm by 91 cm by 70 cm tall was positioned against the bench, centered to the computer monitor. Individuals were seated, in front of the computer monitor, in a chair (48 cm tall) to the left of the tabletop, with the back of the chair aligned with the front left corner of the table. Participants positioned their right forearm on a foam pad (46 cm by 28 cm by 2 cm) concealed with black fabric. The foam pad was located in front of a one-axis load cell force transducer (model LCEB-10, Omega Engineering Inc., Stamford, Connecticut) affixed to the upper left corner of the tabletop. The force transducer was mounted on a wooden block (in order for the force transducer to be at the approximate height of a fully extended index finger) while the arm rested on the foam pad. Participants rested their right index finger lightly on the pressure pad of the force transducer, which was in turn wired to a customized force threshold detector. The threshold detector was calibrated with a minimum threshold level of 0.78 Newtons (N)[1]. Once this threshold was exceeded, both stimulus displays and the recording of transducer depressions were triggered. A second computer was used to run customized software designed upon LabVIEW software (National Instruments Corporation, Austin, Texas) and recorded all relevant dependent measures. The second computer was placed to the left of and slightly behind where participants were seated (see Figure 1).

Procedure

Trials were introduced with the image of a fisted hand grasping a pair of dice. Participants were instructed to initiate dice rolls following a pure tone auditory signal of 800 Hz and 100 ms duration, by depressing the pad of the force transducer. The final image displayed on the monitor was a pair of dice revealing the outcome of the roll. Figure 2 illustrates an example of the dice rolling images in the temporal order that was displayed to participants. Images were displayed continuously as to give the illusion of a

[1] Initial pilot study results confirmed the weight of a resting index finger on the force pad to be approximately 0.78N, which was in line with the findings of Lyons et al. (2007).

hand rolling a pair of dice. All groups were provided with five practice trials at the start of the experimental protocol that served as a familiarization period with both the force transducer and dice rolling procedure. A second baseline threshold of 4N [2] was set on the threshold monitor. Groups differed according to the force-dice outcome relationship presented and the second baseline determined from which outcome list results were selected. The Congruent group was presented with force – dice outcome pairings that were hypothetically consistent with respect to participants' force generation (high/low force) and dice outcome (high/low numbers). Specifically, a force greater than 4N triggered the dice outcome to be selected from a list of "high numbers" from which there was a 67% likelihood of 10, 11, or 12. A generated force of less than 4N, on the other hand, resulted in an equivalent probability of a "low number" outcome (numbers 2-4). Conversely, the incongruent group experienced the reversed force-dice outcome relationship, with an incongruous pairing between the transducer force and dice outcome (i.e., greater than 4N yielded a 67% probability of low numbers and vice versa). Participants in the control group were presented with dice outcomes that were entirely independent of transducer force and were randomly selected by E-prime.

Participants completed a total of two experimental sessions. At the start of the first session, individuals were shown a series of instructional screens that described the virtual dice rolling procedure. Participants were informed of the payout schedules used during each of the trial blocks. The force transducer was referred to as a "button" that participants were instructed to press in a similar manner to that of a computer mouse.

[2] The results of Lyons et al. (2007) revealed an average baseline force of 4N for transducer depressions across all participants.

Transducer depressions were requested to be made after the auditory cue. Following the practice trials, the second block of trials was initiated wherein participants were given 20 five-cent value poker chips. Block 2 consisted of 10 trials during which these poker chips were used to wager on a specific dice outcome: either high (10, 11, or 12), or low (2, 3, or 4). For all three groups, the outcomes presented during the second block were completely random (i.e., the number displayed at the end of each trial was fully independent of the force generated to initiate the trial). Participants were requested to wager a minimum of one poker chip per trial and were informed that they would be able to keep any monies "won" at the end of the experiment. For the subsequent two blocks of trials, participants were given 40 poker chips ($2 value). A specific payout matrix was used for each block, which rewarded or penalized chips according to the outcome. The High Matrix awarded participants for high outcome rolls (10-12) and penalized for low outcome rolls (2-4), while the reversed payout schedule was used for the Low Matrix (see Figure 3). Participants were requested to roll either a high or low number during the third block while the opposite outcome was requested in Block 4. Throughout the third and fourth blocks, the trial outcomes were dependent on group (i.e., Congruent, Incongruent, or Control) according to their assigned force-outcome relationship. Participants were either "penalized" (wagered chips were lost) or "awarded" additional chips based on the outcome of their dice roll against the payout matrix in use at that time.

At the start of Block 5, participants were given an additional 20 poker chips to wager on a specific outcome. The outcome requested was identical to that of Block 2. For all blocks, participants were reminded that any additional monies "won" during the experiment would be given to them at the end of the second session.

The order of requested dice outcomes was counterbalanced between participants within each group. During the first session, the five blocks of trials totalled 169 virtual dice rolls.

The second experimental session was conducted 24 hours following Session 1. At the start of Session 2, individuals were shown a series of instructional screens that reviewed the virtual dice rolling procedures and payout schedules. Participants were verbally reminded that any monies "won" in Session 2 would be added to their total earnings from Session 1, if applicable. Session 2 consisted of two blocks of trials, serving as a test of retention for the third and fourth blocks from Session 1. The second session was conducted to test whether any patterns of behaviour that emerged during the first session were maintained following 24 hours from the initial experimental session. The stimulus presentation for all trials of the second session was entirely random for all three groups. At the start of the first block, participants were given 20 poker chips and were asked to roll a specific outcome according to either the high or low payout matrix. The second block of trials made use of the reversed payout schedule. Specifically, if participants were presented with a high payout matrix for the first block, the low payout matrix was presented during the second block. The payout schedules were organized to match the payout presentation order used during Session 1.

Following all of the experimental trials, participants were asked to complete a questionnaire regarding their personal perspectives on games of chance, and the current experimental protocol. The questionnaire contained 27 questions, which were divided into three sections. Section 1 (Questions 1-5) consisted of "yes" or "no" type questions that pertained to experience with board games, card games, lottery tickets, gambling, and preference for active or passive participation in games of chance. The second set (Questions 6-23) was comprised of a list of statements related to gambling in general. On a scale from 1 (*do not agree at all*) to 7 (*strongly agree*) participants circled the number that corresponded to their level of accord. The third section (Questions 24-27) included "yes" or "no" type questions which related specifically to the experimental task. Participants were asked whether any performance strategies were employed during the dice-rolling task and if the outcome was believed to be the result of these performance strategies. Specifically, participants were asked if distractions or practice could alter performance (see Appendix).

Dependent Measures

Force Generation Data. The primary measures of interest were Peak Force (PF) and Impulse, which were collected on every trial. The force of each transducer press was recorded for 1000 milliseconds starting at the onset of an auditory cue. PF was the point of maximum force on the recorded force curve. The recorded PF measures are reported in Newtons (N). Impulse was defined as the product of the force (F) generated by the participant upon the force transducer and the time interval during which that force was exerted. If the force changed during the time interval, F was taken to be the average net force over that time interval. Thus impulse measures were derived using the formula: Impulse = $\int F\Delta t$. Impulse was measured and reported in Newton seconds (Ns).

In order to account for anomalous trials, an outlier procedure was performed on all raw data prior to analysis. Specifically, trials in which the outcome measure was recorded to be beyond ± 2 within subject standard deviations (sd) were discarded (0.04%).

Wager Magnitude Data. The number of poker chips wagered during Blocks 2 and 5 was recorded and tallied. The number of chips "won" was recorded for all trials and tallied for each session.

Questionnaire Data. The responses for Section 1 (Questions 1-5) and Section 3 (Questions 24-27) were tallied according to the number of "yes" or "no" selected. Section 2 (Questions 6-23) consisted of a scale from 1 (*do not agree at all*) to 7 (*strongly agree*). The value indicated was the score given to each response and scores for Section 2 were tallied.

Data Analysis

Session One

Force Generation Data

Assigned Outcome (Payout Matrices Blocks). The PF and Impulse data for the third and fourth blocks were each analyzed using a 3 Group (Congruent, Incongruent, Control) by 2 Assigned Outcome[3] (High, Low) mixed analysis of variance (ANOVA), with Assigned Outcome as the repeated measure. This analysis served to examine group differences in force data and how force generation changed as a function of Assigned Outcome. In order to examine whether the presentation order of the payout matrices

[3] Desired Outcome refers to the Payout Matrix in use per block of trials. Specifically whether a high number (10, 11, 12) or low number (2, 3, 4) was assigned. Each block consisted of 72 trials.

(sequence of requested outcome) influenced PF, a 6 Group (Congruent A, Congruent B, Incongruent A, Incongruent B, Control A, Control B)[4] x 2 Assigned Outcome (High, Low) mixed ANOVA was conducted. Preliminary results revealed no significant main effects or interactions for presentation order. As such, the sequence of requested outcomes was omitted from further force data analysis.

In order to examine potential changes in force as a function of assigned outcome as well as time (i.e., familiarity with the task as trials progressed), 12 trials from the beginning and end of each PF and Impulse block were analysed in a 3 Group (Congruent, Incongruent, Control) by 4 Time (High: Early, Late, Low: Early, Late) mixed ANOVA with Time as the repeated measure.

Participant Determined (Wager Blocks). The PF and Impulse data for the wager trials (Blocks 2 and 5) were each submitted to a 3 Group (Congruent, Incongruent, Control) by 2 Wager Time (Pre, Post) mixed ANOVA with Wager Time as the repeated measure. This analysis was performed to examine whether there were group differences in force generation when participants were able to select the amount to wager. Since wagers were placed solely on one outcome, either high or low, further analysis was conducted to examine whether force data was influenced by the assigned outcome. This analysis was conducted using a 2 Group (Wager High, Wager Low) x 2 Wager Time (Pre, Post) with Wager Time as the repeated measure. In some instances, the requested outcome specified in Blocks 2 or 5 was identical to that requested in the previous or subsequent payout matrix block. To examine whether the order by which the assigned

[4] "A" denotes payout matrices presented in the high-low order; "B" denotes payout presentation in the low-high order.

outcomes were presented influenced force generation, force data was submitted to a 6 Group (Congruent A, Congruent B, Incongruent A, Incongruent B, Control A, Control B) by 2 Wager Time (Pre, Post) mixed ANOVA with Wager Time serving as the repeated measure.

Wager Magnitude Data

Participant Determined (Wager Blocks). To assess whether the average number of chips wagered varied between the "pre" and "post" wager blocks, the mean number of chips wagered was submitted to a 3 Group (Congruent, Incongruent, Control) by 2 Wager Time (Pre, Post) mixed ANOVA, with Wager Time as the repeated measure.

Total Chip Earnings Session One. The total number of chips won during the first session was analyzed using a 3 Group (Congruent, Incongruent, Control) by 1 Chip Earnings (total amount) mixed ANOVA.

Session Two

Force Generation Data

The PF and Impulse data for the second session[5] were each analyzed in a 3 Group (Congruent, Incongruent, Control) by 2 Assigned Outcome (High, Low) mixed ANOVA with Assigned Outcome the repeated measure. To assess whether the total number of chips earned during the first session influenced force generation during Session 2, this analysis was repeated with the total number of poker chips "won" during Session 1 entered as a covariate.

[5] Each block consisted of 20 trials.

To examine whether force generation differed between Session 1 and Session 2, data were submitted to a 3 Group (Congruent, Incongruent, Control) by 4 Session Assigned Outcome (Session 1:[6] High, Low, Session 2: High, Low) mixed ANOVA with Assigned Outcome as the repeated measure. In particular, the analysis served to determine whether participants displayed any reliable or consistent patterns in force generation during the first session that were replicated in the second session.

Questionnaire Data

Section 1 (Questions 1-5) and Section 3 (Questions 24-27) were each subjected to a Chi Square analysis to determine whether the frequency of "yes"/"no" responses differed from chance. The second section (Question 6-23)[7] was submitted to a 3 Group (Congruent, Incongruent, Control) by 1 Question Section mixed ANOVA.

Preliminary analysis revealed no group differences in the practice trials therefore practice trials were not included in the analyses. Tukey's HSD post hoc procedure was employed to examine all significant effects and interactions with α set at $p. < .05$.

[6] Since Session 2 consisted of 20 trails per block, only the last 20 trials of the first session were used for comparison.
[7] Given the numerous responses of confusion from participants, Question 15 was removed from analysis.

Results

Session One

Force Generation Data

Assigned Outcome (Payout Matrices Blocks).

Peak Force (PF). Analysis revealed no main effects. However, a significant interaction of Group and Assigned Outcome, $F(2,29)=3.49$; p .<.05 was evident. Post hoc analysis suggests that, within the Congruent group, a significantly greater mean PF was generated when a high number outcome was desirable when compared to trials in which a low outcome was rewarded. In addition, the mean PF for the Congruent Group was also significantly higher than the PF for the Incongruent Group when a high number outcome was requested (see Figure 4 and Table 1). There were no significant differences between mean PF for assigned outcome blocks for either the Control or Incongruent Group.

The analysis for Assigned Outcome and Time yielded a significant interaction of Group and Time, $F(6,87)=2.37$; p. <.05. Post hoc analysis revealed the Congruent group had a significantly higher PF generation for the early trials in the high assigned outcome block compared to both the early and late trials for the low outcome block. The Congruent group's high outcome block was also significantly higher than both the early and late trials (high outcome block) for the Incongruent group as well as the late trials for both the high and low outcome blocks for the Control group. Significant differences were also found within the Congruent group between the late trials (high outcome block) which had a higher PF than both the early and late trials (low outcome block). Additionally, the PF for the Congruent group late trials (high outcome block) was significantly greater than both the early and late trials (high outcome block) for the Incongruent group and the early trials of the low outcome block. The late trials (high outcome block) and both the early and late trials (low outcome block) for the Control group were significantly lower than the late trials (high outcome block) for the Congruent group (see Figure 5 and Table 2).

Impulse. As with Peak Force, Impulse data did not reveal any main effects. Analysis however, showed a significant interaction of Group and Assigned Outcome, $F(2,29)=3.42$, $p. <.05$. Post hoc analysis revealed that for the outcome block in which high numbers were requested, the mean Impulse for the Congruent group was significantly greater than that for the Incongruent group. There were no significant differences within any of the three groups for outcome blocks. The difference between the Impulse for the high and low outcome blocks for the Congruent group fell just short of conventional levels of significance (see Figure 6 and Table 1).

The analyses for Assigned Outcome and Time yielded no effects for Group or Time. The Group by Time interaction approached conventional levels of significance ($p. <.06$: see Table 2).

Participant Determined (Wager Blocks).

Peak Force. The PF of wager blocks analysis revealed only a main effect for Time, $F(1,29)=6.51$, $p. <.02$. The wager trials completed before the payout matrices blocks ("pre" trials) were executed with a higher PF than the wager trials which followed the payout matrices blocks ("post" trials).

Impulse. Data analysis demonstrated a main effect for Time, $F(1,29)=4.77$, *p.* <.05. The impulse was significantly higher for the pre trials than the post trials.

Since the blocks of trials required wagers to be placed on only one outcome (high or low), force generation data were further analyzed according to the requested outcome (high or low). Analysis revealed main effects for Type of Wager, $F(1,30)=6.28$, $p < .02$, and Time, $F(1,30)=5.44$, $p < .03$. Impulse was significantly higher when wagers were placed on a high outcome than bets placed on low number outcomes (see Figure 7). The impulse for the "pre" trials prior to payout schedule blocks was significantly higher than the impulse for the post trials.

Wager Magnitude.

Assigned Outcome (Payout Matrices Blocks). For the total number of chips earned in Session 1, the analysis revealed a main effect for Group, $F(2,29)=3.70$; $p < .04$. At the end of the first session, the Congruent group "won" significantly more chips than did the Control group (see Figure 8).

Participant Determined (Wager Blocks). There were no significant main effects or interactions for analyses examining the Number of Chips wagered by Group, by Type of Wager (high, low), or the average number of chips wagered.

Session Two

Force Generation Data

Assigned Outcome (Payout Matrices Blocks).

Peak Force. Analysis revealed no significant main effects or interactions for Group or Assigned Outcome. When earnings from Session 1 were entered as a covariate, the results did not reach significance (see Table 3).

The analysis for Session 1 versus Session 2 PF data revealed a significant interaction for Group by Time, $F(6,87)=2.99$, *p.* <.011. The PF for the Congruent group in the first session (high outcome trials) was significantly higher than the low requested outcome trials for both the first and second sessions. The Congruent group PF for Session 1 high outcome trials was also significantly higher than was the Control group Session 1 high and Session 2 low outcome trials. Additionally the Congruent group Session 1 high outcome trials were significantly higher than the PF for the Incongruent group high outcome Session 1 and 2 trials (see Figure 9 and Table 3).

Impulse. The analysis revealed a main effect for Assigned Outcome, $F(1,29)=9.31$, *p.* <.005. The impulse was significantly higher when the assigned outcome was a high number compared to when a low number was rewarded.

Data analysis comparing Impulse from Session 1 with Session 2 revealed no main effects. The Group by Time Level interaction was just short of conventional levels of significance (*p.* < .06).

Questionnaire Data.

The non-parametric analyses for Sections 1 and 3 revealed no relationship between Group and Response (see Table 4a). The analysis for Section 2 revealed no main effects or interaction for response scores (see Table 4b).

Discussion

This study used a virtual dice rolling paradigm to examine the strength of the illusory control effect. Specifically, we sought to ascertain whether the strength of the illusion was such that it influenced the degree to which traditional stimulus-response associations were learned. To achieve this goal, a stimulus-response learned association protocol was designed in which the force-outcome relationship in the dice rolling task varied between groups. Of particular interest were the conditions in which the degree of force generated by participants resulted in either congruent (high force generation = high dice outcomes/low force generation = low dice outcomes) and incongruent (high force generation=low dice outcomes/low force generation=high dice outcomes). Unlike similar previous studies in which the outcome was wholly independent of force generated (e.g., Lyons et al., 2007), it was hypothesized that in this case the influence of the illusion of control would result in a situation wherein the learned association between response and outcome would develop at differential rates. Specifically, in the congruent condition, participants would learn very quickly that by generating specific force parameters, those behaviours would be rewarded. Conversely, the incongruence of having to generate high forces to achieve low dice outcomes (and vice versa) would have the effect of delaying the learning of these particular stimulus-response associations. In other words, individuals would be motivated to produce a specific response they believed to be more appropriate to achieve the desired outcome. Responses would be driven by the need to maintain a degree of conceptually compatible control over the outcome.

Effects of Payout Matrices on Force – Manipulated Outcomes

Analyses of the experimental results suggest that force production was influenced by the assigned outcome. The effect of specified outcome on force however, was indeed dependent on the force-outcome pairing with which participants were presented. Specifically, only when a congruous force-outcome relationship was presented was there a significant difference in force generation relative to the assigned outcome. Specifically, when the assigned outcome was a high number, dice rolls were initiated with a significantly higher peak force compared to when the assigned outcome was a low number where significantly less force was generated to initiate dice rolls. These results were only partially consistent with previous findings (e.g., Lyons et al., 2007). In the current study it was found that when a high number was the requested outcome, the Congruent group generated a higher PF compared to when a low number was assigned. These results, however, were not observed in the Incongruent group or when the outcome was independent of force (i.e., Control group). In both of these latter groups, no significant difference in PF was found with regard to the assigned outcome. Interestingly, when a high outcome was requested, the Congruent group elicited responses with a significantly higher PF than the Incongruent group. Conversely, when a low number was the assigned outcome, group differences in PF were not found.

In order to determine whether the sequence of requested outcomes influenced force generation, an additional analysis was conducted which examined PF as a function of the order in which assigned outcomes were presented. Data were submitted to a 6 Group (Congruent High, Congruent Low, Incongruent High, Incongruent Low, Control

High, Control Low) x 2 Assigned Outcome (High, Low) mixed ANOVA, with Assigned Outcome as the repeated measure. The analysis revealed no significant effects or interactions suggesting that differences in PF between the Congruent and Incongruent groups during the high outcome blocks could be the result of diverse strategies employed during virtual dice rolls. Analysis of other motor parameters in addition to PF may further explain differences in behaviour between the Congruent and Incongruent groups.

Similar results were observed in the impulse data. When a high number was the requested outcome, the mean impulse of transducer depressions was significantly higher for the Congruent group than for the Incongruent group. Similar to the PF results, no differences in the impulse of force generation was found for either the Incongruent or Control group when a high number was the assigned outcome compared to when a low number was assigned. The results suggest that reward schedules alone were not influencing force production strategies for either the Incongruent or Control group. Although not statistically significant, the results for the Congruent group revealed a slightly greater impulse when a high outcome was favourable compared to trials where a low outcome was requested. Unlike the other two groups, the Congruent group appeared to modify their force production strategies to coincide with the requested outcome. A larger sample group size may provide greater statistical power in order to make more definitive conclusions regarding the relationship between impulse and assigned outcome.

The force data was further analysed as a function of time (i.e., first and last 12 trials per block). Comparable results were observed for the PF of the Congruent group. The PF in the high assigned outcome block (both early and late trials), was significantly higher than the PF in the low outcome block at both the early and late time periods. These results suggest that the Congruent group did not gradually adjust motor responses over the course of the different blocks but rather, right from block initiation, different force production strategies were employed that were consistent with the outcome being requested. More specifically, when a high outcome was assigned, a different force generation technique was employed when compared to trials where a low outcome was requested. In contrast, the results for both the Incongruent and Control groups suggest the use of relatively consistent force generation strategies across assigned outcome blocks. In particular, there were no significant differences in PF between the high outcome block and low outcome block at either time periods (early or late), for either the Incongruent or Control group. These results further emphasize the possibility that alternative strategies (e.g., longer response initiation latencies), other than simple force generation, were guiding the behaviour of the Incongruent and Control groups. The extent to which groups were becoming aware of the force-outcome manipulations, and if so, whether they were learning the required response to optimize their chances of winning remains of interest. Although within-group differences were only found for the Congruent group, it is possible that participants in the Incongruent and Control groups were not becoming aware of the manipulations until too late into the block and consequently, was not observed during Session 1. Studies examining additional movement parameters (specifically both kinetic and kinematic parameters) may provide further insight into whether the Incongruent and Control groups were adopting other movement strategies, besides force generation, when presented with the assigned outcomes.

When the impulse data were analysed to examine whether any differences could be related to the impulse of transducer depressions, the analysis revealed no effects or interactions. Any variations in force within or across groups were not time dependent. There were no differences in the duration that forces were applied early or late in blocks regardless of whether the assigned outcome was high or low.

The results from the first session suggested that there were differences in PF according to group (i.e., Congruent versus Incongruent and Control groups) however, if groups were learning the correct strategies to be employed at the end of each block, it would be expected that these strategies would be utilized during the second session. Furthermore, the Congruent group was the only group in which the responses for one block of trials were significantly different from that of the second block. The Incongruent group and Control group did not display any within-group differences. Although the strategies may be different between the Congruent and Incongruent group, these results may suggest that any strategies that were employed by the groups may have differed within groups (i.e., the motor production strategies employed). While the results found that the Congruent group varied PF generation according to assigned outcome, it is possible that the other groups, in contrast, may have been adjusting movement parameters that were not being recorded during the current experiment (i.e., reaction time/response time, number of button presses).

Effects of Payout Matrices on Force – Random Outcomes

During the second experimental session, all groups were presented with random outcomes, independent of force. Contrary to Session 1, no main effects or interactions for PF were observed. For the Impulse data, however, a main effect for assigned outcome was found. The high assigned outcome block was found to have a significantly higher impulse than the low assigned outcome block. The lack of significant difference in PF suggests that if groups were using specific strategies during the first session, these were abandoned during the second session in favour of a response more appropriate to attain the assigned outcome. Participants, in particular those in the Congruent and Incongruent groups, may have realized early during the second session that the outcome was no longer related to force generation as was previously observed during Session 1, despite using the same technique. Accordingly, the main effect for Impulse suggests that different strategies may have been employed for the high assigned outcome block compared to when the assigned outcome was a low number. These results are consistent with previous findings (e.g., Lyons et al., 2007), in which higher impulses were generated for high numbers and lower impulses for low numbers.

The different results between the first and second session raises the question as to whether the force-outcome relationships, in particular for the Congruent group, were learned in accordance with the force-outcome relationship presented, or whether these were intrinsic motor responses that were adjusted based upon the feedback received. It is possible that within a small number of trials, if participants became aware that their strategy was no longer successful, they may have sought out an alternative strategy that was more effective. The impulse data for the second session could suggest that while the absolute force of transducer depressions may not have seemed essential in the attainment of the desired outcome , participants may have varied their response time in relation to the assigned outcome. This implies the use of a different motor response during the second session, possibly an attempt to change, or "control" the outcome. If participants perceived that the dice outcome presented was unrelated to their dice rolling behaviour, then it would be expected that the behaviour would be similar across all sessions. There would be no benefit for participants to change the manner in which they pressed the force transducer because they would perceive it to have no influence on the outcome. The results from the first and second sessions, however, demonstrates that some groups altered their force production strategies according to the feedback with which they were presented, possibly in an effort to "control" the outcome.

Effects of Self-Selected Wagers on Force

When participants were able to select the amount of poker chips to wager for each trial, the PF was significantly higher during Block 2 ("pre"), prior to the use of the payout schedules, compared to Block 5 ("post"), which was completed after the assigned outcome (payout matrices) blocks. These differences in PF, however, were not related to group or to the assigned outcome, whether wagers were made on a high or low number outcome. These differences could be attributed to familiarity with the equipment and dice rolling procedure, where in Block 2 there were only five practice trials by which it was preceded, where as in Block 5, participants had already completed 159 trials.

Alternatively, the impulse data revealed a significantly higher impulse for individuals who wagered on a high outcome compared with those who placed wagers on a low outcome. These results may be indicative of diverse strategies, or motor plans, used during the trials which were dependent on specified outcome. Strategies may have included button presses held over a longer period of time, or executed with more force over a shorter period of time. Participants may have tested different force-time couplings in an attempt to influence the outcome of their dice roll. The correct response would not have been obvious to participants as all groups were presented with random outcomes during Blocks 2 and 5. Regardless of what strategies may have been employed, the Impulse data provides support that all participants varied force generation according to the assigned outcome, suggestive of an attempt to exert control over a completely random outcome. Since participants only wagered on one specific outcome, it is not clear whether within group variations would be present if participants had wagered on both high and low outcomes.

Effects of Wins and Losses

The analysis of poker chip earnings revealed that the Congruent group won the largest number of poker chips at the end of the first session, significantly more than the Control group. These winnings were not found to influence responses during the second session. These results raise the issue as to whether the poker chips were affecting the motive to control. For example, for the Congruent group, it is possible that the winnings may have been partially driving the behaviour, in particular during Session 1. In this manner, winning may have amplified the sense of control, as the chips were stacked in front of the participants, where they were able to watch as their earnings increased, reinforcing the behaviour. On the other hand, a reduction in chips, may have contributed to a sense of loss, increasing frustration as the participants were very much aware of how many chips they were losing. If the losses were occurring later in the trials, the participant may have had a sense of "hopelessness" in recovering the lost chips before the experiment was over, giving up any sense of control and attributing outcomes entirely to chance (e.g., Seligman & Maier, 1967). In this manner, they may have concluded that any action, in an attempt to influence the outcome, would have been irrelevant as the outcome was the result of chance. In this sense, forfeiting whatever "control" they may or may not have perceived depending on the experimental group in which they were placed.

The results further suggest that the Congruent group had learned the force-outcome relationship they were presented, demonstrated by the greater force generation for a high number outcome and lesser force for a low outcome. Although their earnings in chips suggests that they were aware of this relationship, it is not clear whether the Congruent group learned the appropriate response based on the high number of earnings, or whether their force responses were entirely based on previously learned S-R associations (e.g., Romaiguère et al., 1993). On the other hand, the other groups were less successful in winning chips, in particular the Control group. If participants continued to win chips it would reinforce that their behaviour was correct.

Questionnaire Responses

The questionnaire results did not reveal any differences among the three experimental groups. These results suggest that participants' motor responses during the task differed from their perceptions after the task. This discrepancy between illusory behaviour and perception is consistent with previous studies concerning the illusions of control (e.g., Langer, 1975). The absence of any reliable effects in the analyses of the questionnaire data suggests that any preconceived opinions or attitudes towards gambling or chance situations are inconsequential with respect to the behaviours expressed in this study.

General Discussion

A fundamental tenet of theories of Associative Learning is that behaviours resulting in a positive outcome will be learned rapidly and will be repeated whereas those that do not will be resistant to learning and will not be maintained. The primary purpose of this study was to determine the degree to which the Illusion of Control may serve to mediate this usually robust relationship. The nature of the task employed in this study was such that clear reward ratios were established for specific behaviours. It was hypothesised that if the Illusion of Control does not exist (or is weakly expressed) there will be little or no difference in the rates of learning between reward conditions in which either high *or* low force generation results in high number outcomes (and vice versa) as long the rewards for these behaviours are consistent. If, on the other hand, the Illusion of Control creates a situation in which a given behaviour (e.g., high force generation) results in a conceptually incompatible outcome (e.g., a low number dice roll) the association between these stimulus-response pairings would be resistant to learning.

The results of the study provide some support for this hypothesis and suggest that participants may have been using outcome dependent strategies when generating virtual dice rolls. Specifically, when individuals were presented with hypothetically incongruous S-R pairings or pairings that were independent of force, there were no differences observed in the maximum force exerted during transducer presses, regardless of the outcome requested (e.g., high or low). Conversely, when a hypothetically congruous force–outcome pair was presented, force generation was significantly influenced by the assigned outcome. For example, when a high number was requested, transducer depressions were executed with a higher peak force, while the opposite was observed when a low number outcome was assigned. Additionally, the relationship between force generation and requested outcome varied with the task demands. Specifically, force–outcome relationships varied with the duration of the task (Session 1 versus Session 2) and the style of payout, whether it was an assigned payout schedule (payout matrices used), or wagers were participant determined. While the current study revealed that dice rolls were completed differently under diverse payment schedules, the exact mechanism of change and the reason for the differences in dice rolling behaviours remains to be determined. An investigation into the use of different strategies (e.g., changes in both kinetic and kinematic movement parameters) may provide a greater understanding of behaviour in chance situations.

Learned Response and Population Stereotype

Explanations for response selection to various stimuli have been offered in stimulus–response compatibility literature. Compatibility has generally been acknowledged as an effective match, or congruence, between the environmental inputs (stimulus) and an individual's response, whether psychological or physical in nature (Small, 1977). The effective pairing of stimulus and response enhances human performance, leading to successful and efficient task execution. Recalling previous compatibility literature, Fitts and Seeger (1953) suggested that the speed and accuracy of responses were dependent on the relationship between the presented stimuli and the required response. For example, when the light array (stimulus) and movement direction (response) were similar, the speed and accuracy of responses were superior to trials where stimulus and response sets were diverse. A finding of particular interest was that performance errors persisted despite extensive practice. The authors concluded that individuals have difficulty learning the appropriate response when it is uncharacteristic of what has been previously learned in similar situations. This would suggest that individuals do not necessarily execute the "ideal" response, but rather a response that is the product of previous experience. Fitts (1951) termed preferential response selection as population stereotype where a particular response is selected repetitively despite response alternatives. Unlike stimulus-response compatibility, which is the speed and accuracy with which a response is executed, population stereotype is the likelihood that a particular response is selected over the available alternatives (Kantowitz, Triggs, & Barnes, 1990). Additionally, population stereotypes have been shown to be influenced by culturally learned associations and expectations (see Smith, 1981; Courtney & Chan, 1998; Yu & Chan, 2004). Learned stimulus-response associations have been further demonstrated using varying intensities of visual stimuli (i.e., Romaiguère et al., 1993), and numerical magnitudes (i.e., Moretto & di Pellegrino, 2008). Reactions times to light intensities were faster when compatible stimulus-response pairs were presented (i.e., strong button press paired with a bright visual stimulus and a weak press required for a dim stimulus) compared to presentations of incompatible pairings (i.e., strong press paired with dim visual stimulus and weak press with a bright stimulus) (Romaiguère et al., 1993). Moretto and di Pellegrino (2008) found compatibility effects between numerical magnitude of presented stimuli and the speed of hand grip responses. Hand grips were executed faster when a power grip (associated with holding large objects) was paired with the presentation of large magnitude numbers while the precision grip (associated with picking up small objects) was faster when coupled with small numerical magnitudes (see also Lindemann et al., 2007). It would appear that previous experience with presented stimuli influenced response selection. Given the prominent role of numerical information in daily life, it would not be surprising cultural influences and learned associations would impact human interaction with numerical stimuli (McCloskey & Macaruso, 1995).

Numerical associations have also been demonstrated in a stereotyped compatibility effect found between numerical magnitude and response force, where the force to initiate virtual dice rolls was related to the magnitude of the assigned outcome (Lyons et al., 2007). The behaviour persisted despite participants' observations that the force generated to initiate trials was unrelated to the outcome displayed. The behaviour was suggestive of illusory control; participants attempted to control the outcome despite the fact that the outcome was arbitrary and therefore, unrelated to their actions (Langer, 1975). Contrary to the results of Lyons et al. (2007) a compatibility effect between the numerical magnitude of the assigned outcome and response force was not replicated in the first session of the current study. The Control group, who was presented with arbitrary dice outcomes during Session 1 and the Incongruent group who was presented with incongruous force-outcome pairings, generated a relatively consistent PF regardless of the outcome requested. These results suggest that the Illusion of Control may not be ingrained since it was not demonstrated by all groups, and raises the possibility that illusory control can be modified through learned associations.

The Congruent and Incongruent groups were presented with manipulated force-outcome pairs in order to determine whether illusory control can be modified through learning. The results for the Congruent group for Session 1 were suggestive of a learned association as the PF generated was related to the magnitude of the assigned outcome. When a high number was favourable, a significantly higher PF was generated compared to when a low magnitude outcome was assigned. If the behaviour of the Congruent group was learned over the course of the task, then the Incongruent group should have displayed behaviour opposite to the Congruent group given the opposite, incongruous force-outcome pairs with which they were presented. This, however, was not found as the Incongruent group displayed behaviour similar to that of the Control group, with relatively consistent PF across all blocks of assigned outcomes. Consequently, these results do not demonstrate an illusory control effect, and more specifically, the behaviour of the Incongruent group does not suggest that the "correct" force-outcome pairings were learned. If the results for the Congruent group were indicative of an inherent illusory effect, it would be expected that the behaviour exhibited by the Congruent group during Session 1 would be repeated in Session 2 despite outcomes being independent of force generation. Conversely, if the behaviour was learned, it is possible that behaviour could have been adjusted in accordance with the outcomes presented and therefore, could resemble the behaviour of the Control group.

While the Congruent group behaved in Session 1 as hypothesized, demonstrating a force-outcome relationship that matched the congruous force-outcome pairs with which they were presented, this behaviour was not observed in Session 2. During the second session, the Congruent group generated a relatively consistent PF regardless of the outcome requested, similar to that observed for both the Control and Incongruent group. In the second session however, differences were found with the impulse of presses. A higher impulse was generated when a high number was assigned compared to when a low number was requested. In contrast to the PF data from the first session, differences in impulse were not dependent on group; similar results were found across all participants. The impulse data suggest that for Session 2, all participants approached the dice rolls in a similar manner, regardless performance during Session 1. Furthermore, any variations to the way in which responses were executed may have included movement parameters that were not measured in the current study (i.e., reaction time, response time, number of presses). Response time, in particular, has been found to demonstrate compatibility effects between button press responses to different light intensities (Romaiguère et al., 1993), as well as between numerical magnitude and hand grip responses (Moretto & di Pellegrino, 2008). In the previous studies, stimulus-response compatibility effects were demonstrated with the speed in which the response was generated, not the force of the response. Compatibility effects with response time were also demonstrated more recently by Fischer and Miller (2008) who examined the response time, error, and peak force of button presses on a numerical size judgement, and parity task. It was found that numerical magnitude had an effect on response time however, no effect was found on response force. The authors suggested that numerical magnitude influenced response selection and preparation, but not the execution of the task (i.e., the force generated to execute the task). While previous studies have demonstrated S-R compatibility effects isolated to response time, the results presented here are inconsistent with the results of Lyons et al. (2007) where response force was found to be influenced by the numerical magnitude of the assigned outcome. A possible explanation for this discrepancy may be provided by Fischer and Miller (2008) where participants, in a similar force generation study, were instructed to respond as quickly as possible. This could have resulted in a speed-force trade off where, in order to respond as quickly as possible, the force of the response was attenuated. Although the results of the current study did not replicate the findings of Lyons et al., (2007), the results do suggest that response force was manipulated according to desired outcome even if not in the manner hypothesized. The inconsistency between the first and second session, in addition to the Impulse data from Session 2, suggests that participants were using different strategies, specifically with movement parameters that were not measured in the current study.

Another possible explanation for the results of this study, in particular for the first session, is that of outcome sequence. Langer and Roth (1975) demonstrated the influence of outcome sequence on perceptions of illusory control using a coin toss task. When individuals were presented with a higher number of successful outcomes early in the task, they perceived the outcome to be the result of their actions. Conversely, participants who received a higher number of unsuccessful outcomes early in the task perceived outcomes to be random and not under their control. It is possible that in the current study, all groups approached the desired outcomes as described in Lyons et al. (2007), generating a higher force for a high outcome and less force for a low outcome. Given the force-dice outcome manipulations, the Congruent group would have received a sequence of successful outcomes early in the task, while the Incongruent group would have received a sequence of unsuccessful trials early in the task. It could then be hypothesized that the Congruent group may have perceived outcomes to be related to the force generated to initiate trials. The Incongruent group however, may have been less certain about the appropriate response and may have tried diverse strategies in search of the "correct" response (i.e., response time). During Session 2 the outcomes were independent of force and consequently the Congruent group would not have been presented with the same sequence of successful trials. The Congruent group may have abandoned their previous strategy in search for one that would provide more lucrative outcomes. In trying to determine the response parameters responsible for the outcomes, participants may have applied problem solving strategies, such as heuristics (see Tversky & Kahneman, 1974; Thompson et al., 1998). Individuals may have applied heuristics in order to assess their role in acquiring the outcome. This would have been influenced by their expectations regarding response and outcome, the number of times their actions were followed by a successful outcome, and also their desire for a specific outcome (Thompson et al., 1998). Once applied however, heuristics would be difficult to change and would interfere with the identification of real causation (e.g., Rudski, 2000). For example, if individuals in the Incongruent group did not perceive force as being responsible for the outcome, they may have been attending to another movement parameter, such as response time. Consequently, any trials in which the force of their responses was correctly matched to receive the desired outcome, they may have been unaware of this relationship, under the perception that the assigned outcome was attained because the response was executed within the correct time frame. If participants had previously learned associations regarding force and numerical magnitude, as demonstrated in Lyons et al. (2007), then it may not have seemed logical to participants in the Incongruent group that a small amount of force could possibly yield a high outcome, the reverse for a small outcome. This may have further strengthened the perception of the applied heuristic that another movement parameter was responsible for the outcome.

Goal Directed Approaches

In this study, the results between Session 1 and Session 2, in particular for the Congruent group, raised the question as to whether or not participants were relying on the feedback (i.e., the dice outcome) from their transducer presses to guide their behaviour. More specifically, the PF generation of the Congruent group during Session 1 corresponded to the force-dice outcome manipulation with which they were presented. On the other hand, the Control group (presented with randomized outcomes throughout the entire study) displayed a relatively consistent PF for both assigned outcome levels. If the Illusion of Control is an inherent phenomenon, it would be expected that differences in peak force would be presented regardless as to whether or not the presented outcomes were manipulated or arbitrary. It is possible that feedback may have been guiding behaviour, in particular through the use of forward models. The use of forward models enables the prediction of an outcome before the availability of sensory feedback, producing an estimate of the new state. That is, a set of parameters that determine behaviour (see Wolpert, Ghahramani, & Jordan, 1995; Miall & Wolpert, 1996; Kawato, 1999).

If the overall goal was to win as much money per assigned block, then each dice roll could be thought of as a continuous movement in which adjustments were made to achieve the end result, to win as much money as possible. In terms of internal models, the current state (the outcome) would have been compared with the desired state (assigned outcome). In particular, how the force transducer was pressed for the current outcome would be compared with the response believed to yield the assigned outcome. This would result in a continuous comparison between the outcome (i.e., the current dice outcome) with what *should have happened* (i.e., the assigned outcome) (see Wolpert, 1997). If participants were using forward models to guide their behaviour, then it is not surprising that the Congruent group did not replicate the same behaviour during Session 2 when dice outcomes were randomized for all groups. Contrary to the first session, the PF generated by the Congruent group in Session 2 was not significantly different between high and low assigned outcomes. Since the outcome for each trial during the second session was independent of force, the feedback would indicate that diverse manipulations of movement parameters was required in order to achieve the assigned outcome. If forward models were being utilized in the current study to guide transducer depressions, the Incongruent group should have demonstrated performance during Session 1 opposite to that of the Congruent group, with a higher force when a low number was assigned and less force when high outcomes were requested. This was not observed however, as the Incongruent group did not display any significant differences in force generation according to assigned outcome. These results suggest that the Incongruent group was not relying on feedback to guide the PF of their presses. The impulse data for the second session further highlights movements suggestive of factors not owing to internal models. The data revealed a significantly higher impulse when a large magnitude number was requested compared to when a low number was assigned. These results were not group dependent. The diversity in behaviour across groups during Session 1 and the impulse data of Session 2 suggests that behaviour during the task was not necessarily guided by feedback, but raises the possibility of response compatibility effects. Additionally, the performance parameters that were manipulated may not have been consistent across groups. More specifically, changes in performance parameters may not have been solely manipulations in force generation, possibly owing to other motor parameters influenced by numerical magnitude (i.e., response time).

Time Dependent Illusory Control

The diverse results between the first and second session raises the question as to whether the illusory control effect is time dependent. Was it possible that the first session was too long and consequently the presence of an illusory effect was diminished? Since Session 2 was substantially shorter, did the fewer number of trials facilitate the presence of an illusory effect in the impulse of transducer presses? In early Illusion of Control literature, this phenomenon was observed through the use of a limited number of trials. In particular, Langer and Roth (1975) demonstrated the influence of outcome sequence on perceptions of illusory control in an experimental design which consisted of 30 trials. In contrast to the current study, Lyons et al. (2007) observed an illusory control effect with fewer trials. Their study involved three payout blocks: a low matrix (2, 3, 4), a mid matrix (6, 7, 8), and a high matrix (10, 11, 12). Each block consisted of 24 trials with rewards or losses of 4, 5, or 6 poker chips. Interestingly, illusory control was observed even though participants were presented with arbitrary outcomes, and despite participants observing that force generation did not influence the outcome of the dice rolls. In the current study, it was hypothesized that the Control group would have performed similar to that found in Lyons et al. (2007), since the Control group received the same dice outcome presentation. These results however, were not replicated in the current study. One possible reason for the different findings could be due to the increased numbers of trials in the present study. In the first session there were two blocks of assigned payout schedules each consisting of 72 trails. One payout block in the current study was the length of the entire Lyons et al. (2007) study. Session 2 consisted of 20 trials per assigned payout block. Furthermore, in Session 2, which was much closer to the trial distribution of the previous study, the Impulse of transducer presses was found to be significantly different according to the assigned outcome (i.e., higher when a high number was assigned and lower when a small magnitude number was assigned). In Lyons et al. (2007) since there were only 24 trials per block, participants had a relatively short time frame to roll a specific outcome, therefore, participants had to exert as much "control" as possible in order to attain the assigned outcome. In order to maximize their winnings, participants may have quickly applied heuristics in order to determine the cause for the outcomes. In the present study conversely, there were two payout schedules, high and low, each block consisting of three times the number of trials, totalling 72 trials each. The increased number of trials may not have created a sense of urgency, the perception that participants only had a few trials to try and attain the reward. If they did have a series of losses, they may have felt that there were plenty of trials remaining in order to still "win". As a result, for each trial, there may not have been a sense of risk taking necessary in order to exhibit illusory control (see Langer, 1975). In the illusory control literature, tasks required participants to respond relatively quickly. There were a few number of trials, therefore participants had to get it "right" immediately. Decisions were made on the spot which prevented participants the opportunity to logistically plan their actions. These relatively instantaneous decisions may have also been influenced by motivation during the task. Wortman (1975) has suggested that differences in the level of illusory control can be attributed to the amount an individual is motivated to observe a particular outcome. The amount of motivation is dependent on the value that one associates with the end result, or in the case of the current study, the amount of money won. If motivation is not sufficient, individuals may not feel a "risk" of losing anything and therefore, may become more aware of chance related cues and perceive a lack of contingency between response and outcome. Consequently, the lack of motivation would inhibit the Illusion of Control.

The majority of the Illusion of Control literature was based on studies that had fewer trials than what was presented in the current study. In the Lyons et al., (2007) study everyone received the same response-outcome pairing as the Control group. Specifically, the outcome pairing was independent of the force generated to initiate the trials. This raises the question of participant motivation and whether the Illusion of Control is time dependent. It is possible that the present study consisted of too many trials, and consequently, participants were trying to logically figure out the appropriate response instead of responding based on instinct. In particular, participants may have been testing different strategies (i.e., response time, response duration) in order to determine the "correct" response. Perhaps in Lyons et al. (2007), the motivation and time frame created a situation in which participants were unable to determine a logical reason for the outcome and therefore, created a situation in which responses were immediate, a "gut reaction".

Conclusion

The current study was conducted in order to examine the robustness of illusory control in chance situations and additionally, to examine whether the effect is intrinsic or sensitive to learning. While it was found that peak response force was related to assigned outcome when congruous force-dice outcome manipulations were presented, the results of the current study raise the possibility that the Illusion of Control is a time dependent effect. More specifically, the effect is more apparent when the task is performed within a short time period. The results of the second session data supports the hypothesis that illusory control is time dependent, as was observed with the impulse of transducer presses. This is suggestive that other motor parameters, besides force, may influence dice rolling behaviour. While the current study supports the existence of illusory control in virtual dice rolling, it is apparent that previous experience influences the movement parameters and task execution (i.e., Session 1 performance versus Session 2). Future studies to examine virtual dice rolling behaviour at different durations (i.e., number of trials), as well as a measure of both kinematic (e.g., response time) and kinetic (e.g., force) movement parameters would shed light on how task length influences the perceived response controlling the outcome.

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Table 1.
Session 1: Peak force (PF) and impulse as a function of group and assigned outcome.

		Assigned Outcome	
	Group	*High*	*Low*
PF (N)	Congruent	4.17	1.77
	Incongruent	1.89	2.34
	Control	2.30	2.38
Impulse (Ns)	Congruent	0.93	0.36
	Incongruent	0.31	0.61
	Control	0.48	0.48

Table 2.
Session 1: Peak force (PF) and impulse as a function of group, assigned outcome and time (early, late).

		Assigned Outcome			
		High		Low	
		Early	Late	Early	Late
PF (N)	Congruent	4.14	4.26	2.06	1.84
	Incongruent	2.23	1.92	2.36	2.63
	Control	2.43	2.13	2.41	2.28
Impulse (Ns)	Congruent	0.92	0.98	0.41	0.35
	Incongruent	0.41	0.33	0.64	0.56
	Control	0.49	0.44	0.52	0.59

Table 3.
Peak force (PF) and impulse as a function of group, experimental session and assigned outcome.

		Assigned Outcome Session 1		*Assigned Outcome Session 2*	
	Group	*High*	*Low*	*High*	*Low*
PF (N)	Congruent	4.37	1.62	2.58	2.05
	Incongruent	1.83	2.63	2.09	3.26
	Control	2.18	2.28	2.83	2.58
Impulse (Ns)	Congruent	0.97	0.30	0.53	0.45
	Incongruent	0.32	0.65	0.39	0.25
	Control	0.46	0.44	0.52	0.27

Table 4a.
Frequency of "yes"/"no" responses as a function of group for questionnaire Sections 1 and 3.

Group	*Section 1*		*Section 3*	
	"Yes"	*"No"*	*"Yes"*	*"No"*
Congruent	35	15	7	33
Incongruent	37	13	7	33
Control	33	27	2	46

Table 4b.
Average response scores as a function of group for questionnaire Section 2.

Group	*Section 2*
Congruent	47.90
Incongruent	55.40
Control	52.18

Figure 1

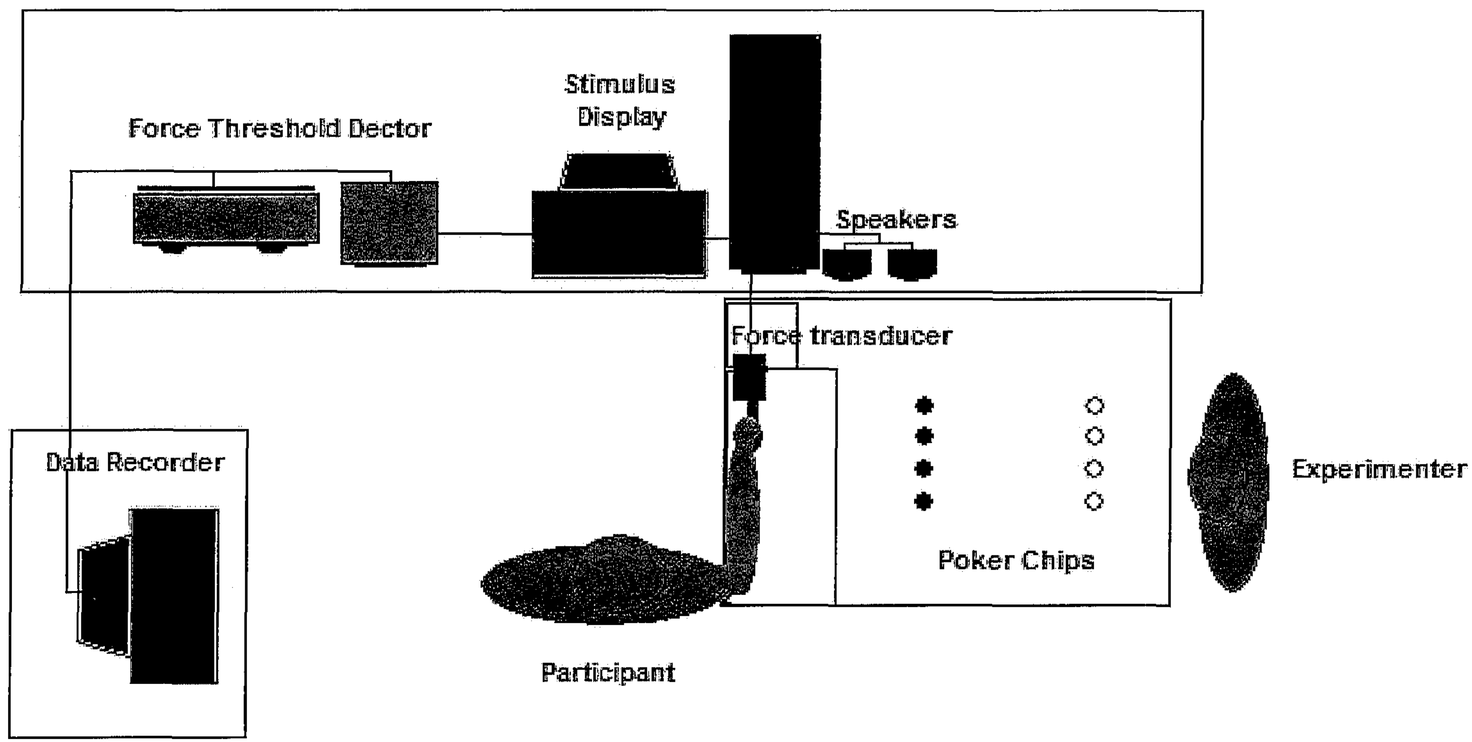

Stimulus
Display
Force Threshold Dector
Speakers
Force transducer
Data Recorder
Experimenter
Poker Chips
Participant

Figure 2

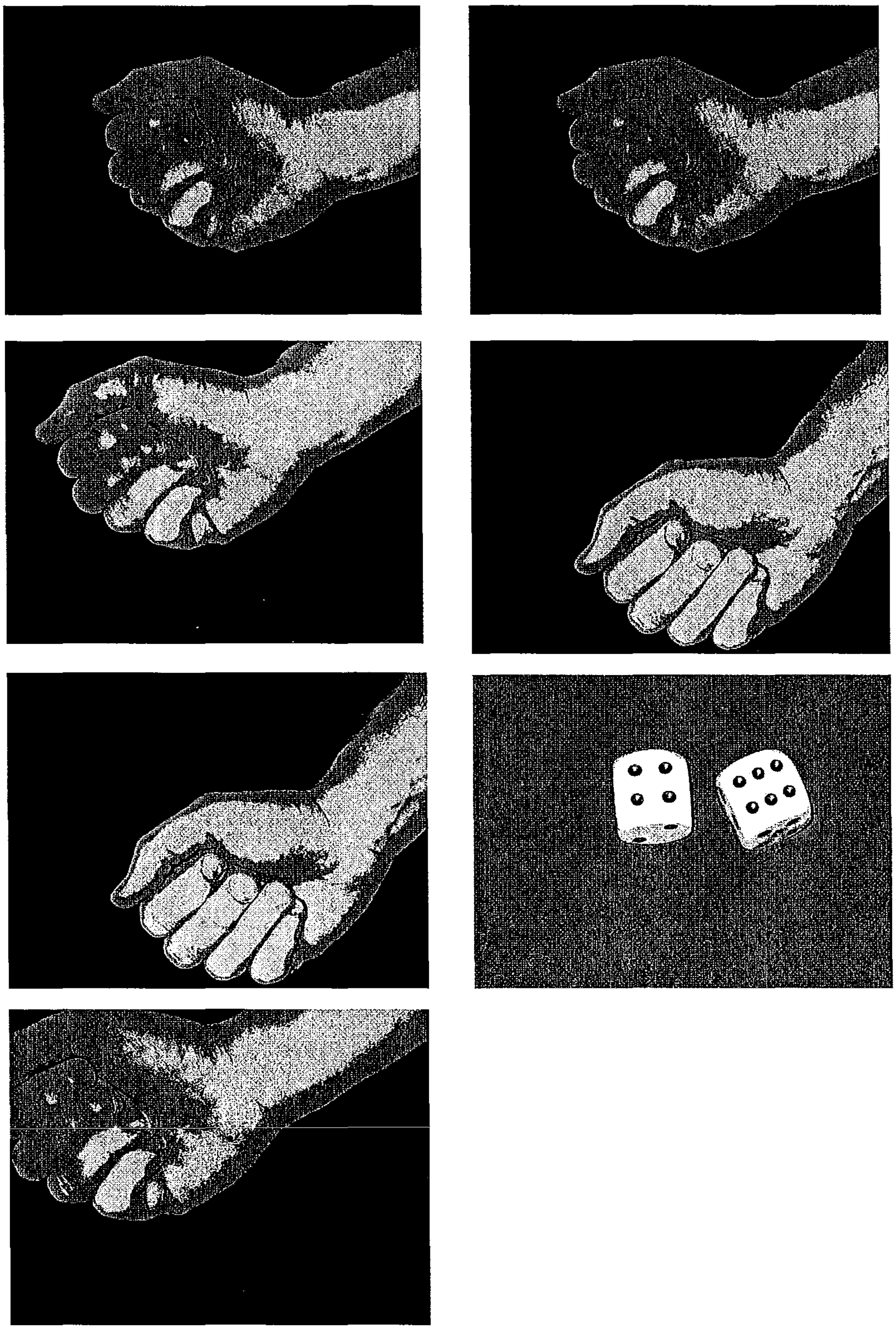
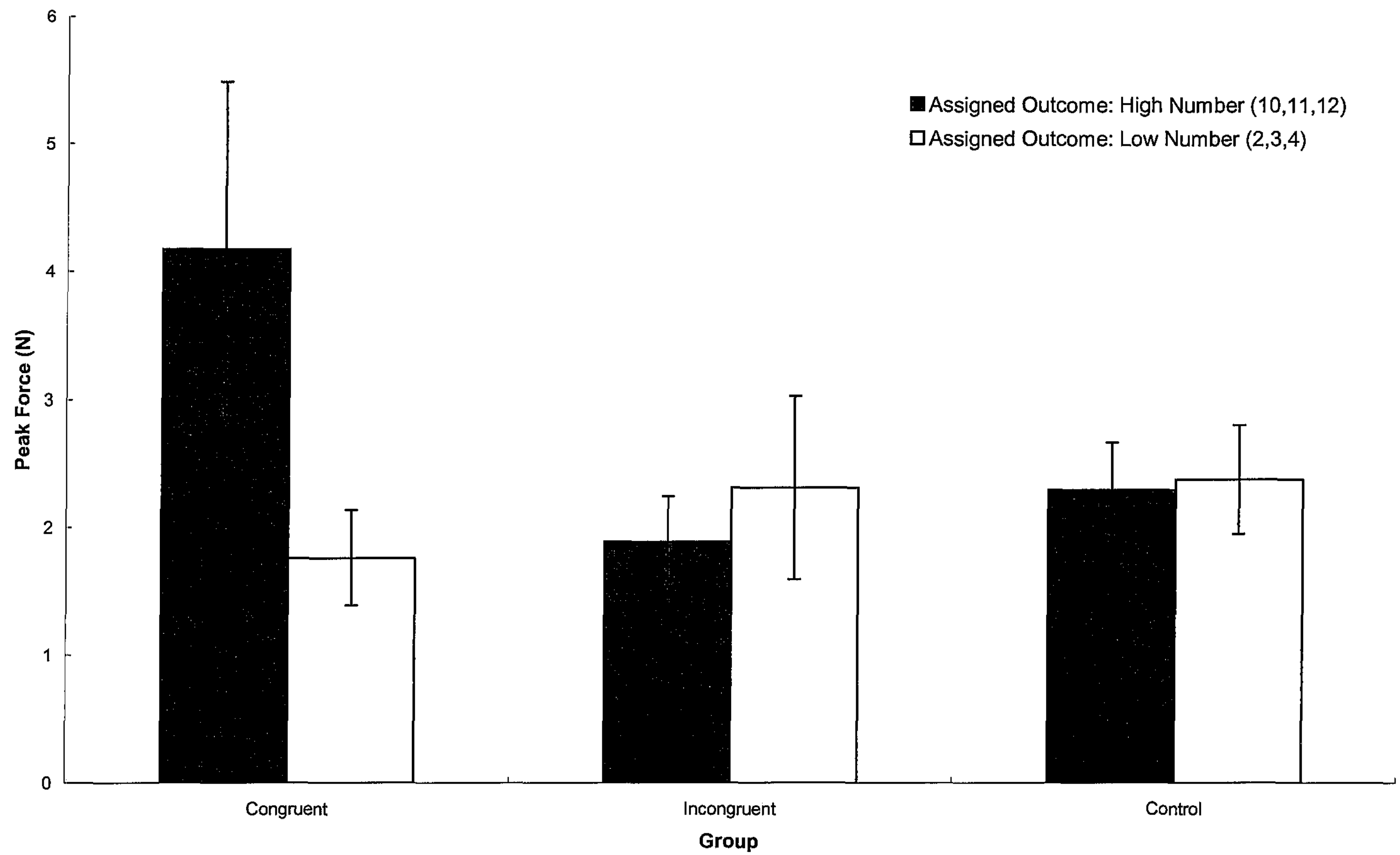


Figure 3

Dice Roll Outcome	Low Matrix	High Matrix
12	**-5**	**+5**
11	**-3**	**+3**
10	**-1**	**+1**
9	X	X
8	X	X
7	X	X
6	X	X
5	X	X
4	**+1**	**-1**
3	**+3**	**-3**
2	**+5**	**-5**

+ experimenter pays participant
- participant pays experimenter

Figure 4



Note: Since the apparatus was configured such that a force of 0.78N was required to initiate each trial, and 4N was the threshold for different outcome selections (high or low) in the manipulated trials, PF data was normalized to this threshold.

Figure 5

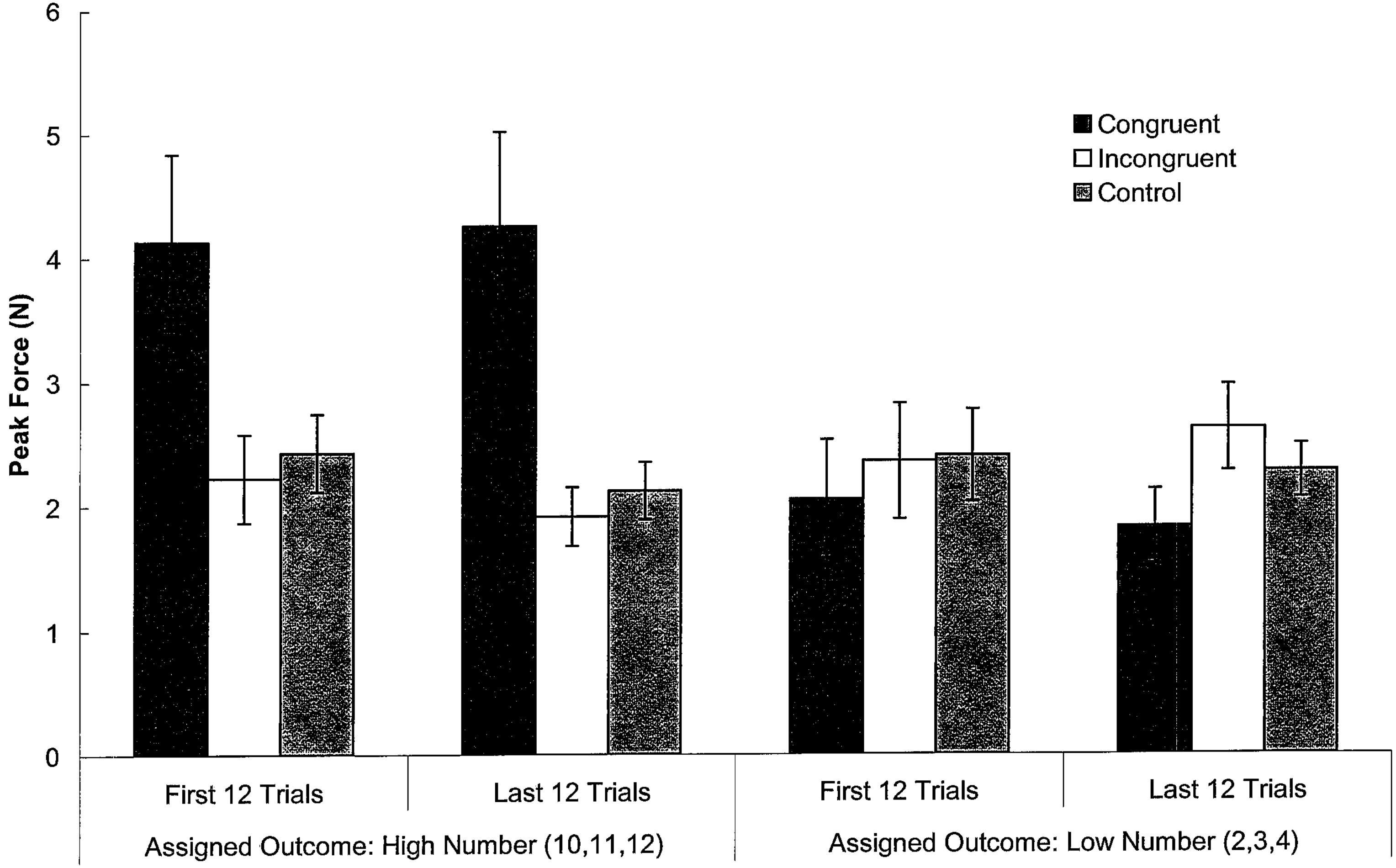

6
5
4
3
2
1
0
Peak Force (N)
Congruent
Incongruent
Control
First 12 Trials
Last 12 Trials
First 12 Trials
Last 12 Trials
Assigned Outcome: High Number (10,11,12)
Assigned Outcome: Low Number (2,3,4)

Figure 6

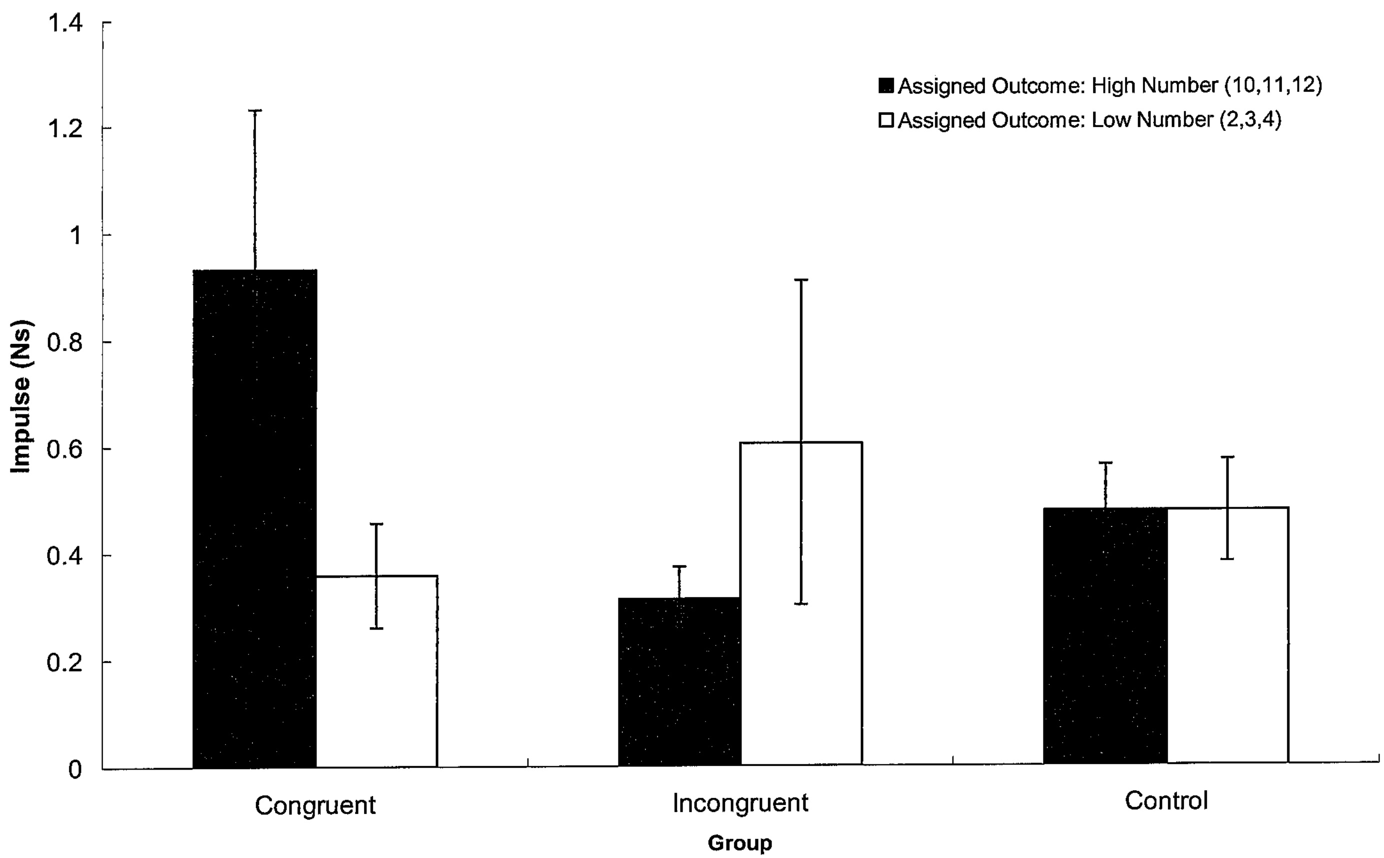

1.4
1.2
1
0.8
0.6
0.4
0.2
0
Impulse (Ns)
Assigned Outcome: High Number (10,11,12)
Assigned Outcome: Low Number (2,3,4)
Congruent
Incongruent
Control
Group

Figure 7

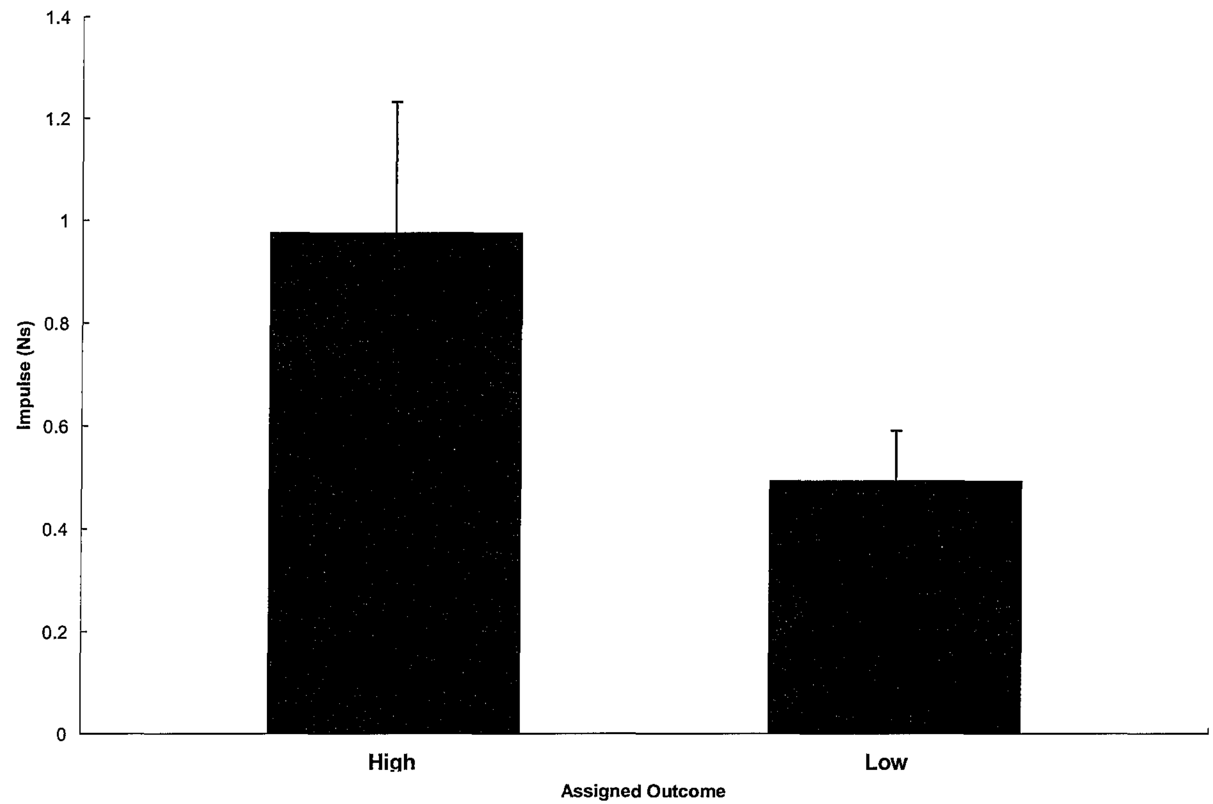


Figure 8

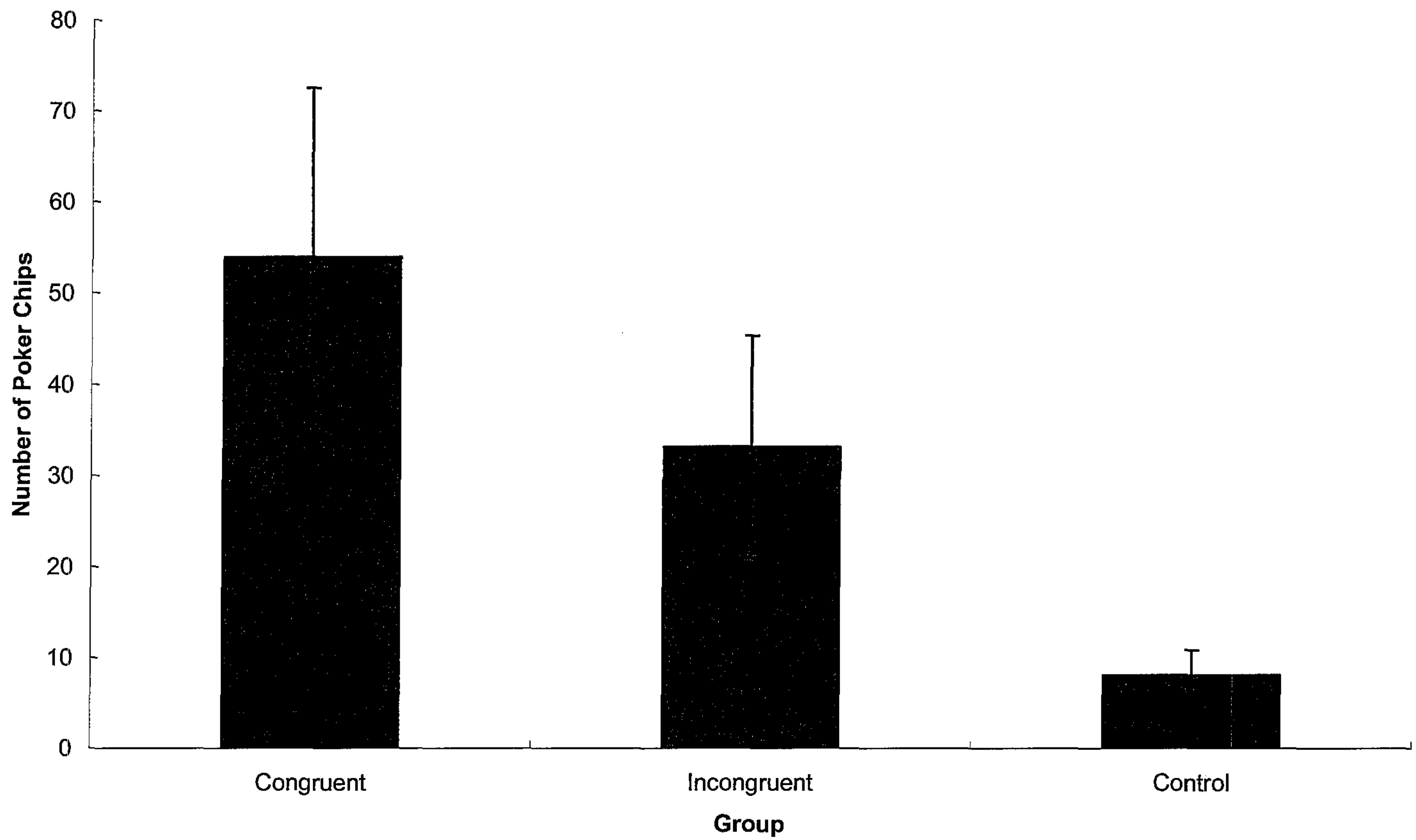
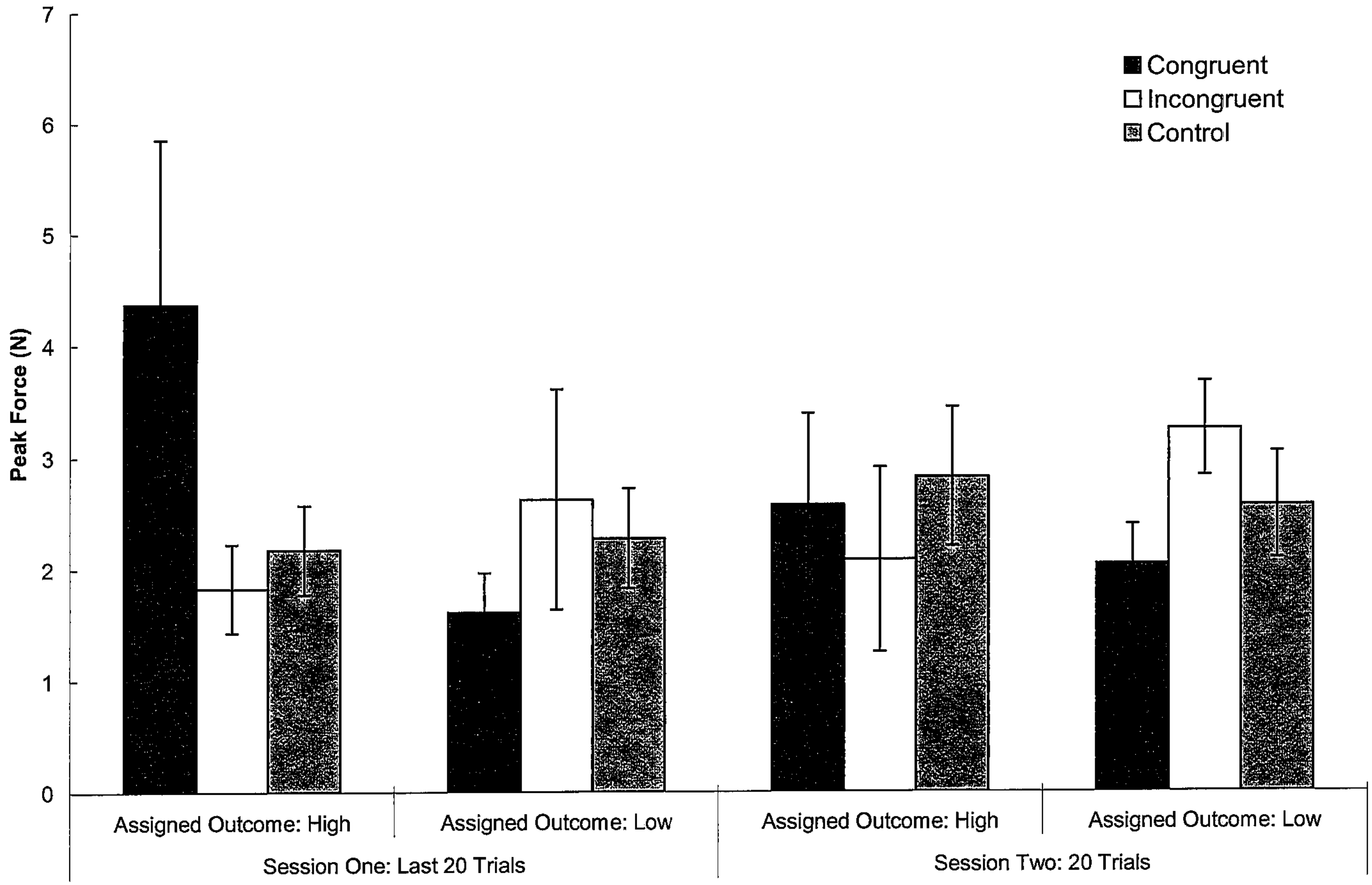

80
70
60
50
40
30
20
10
0
Number of Poker Chips
Congruent
Incongruent
Control
Group

Figure 9


7
6
5
4
3
2
1
0
Peak Force (N)
Congruent
Incongruent
Control
Assigned Outcome: High
Assigned Outcome: Low
Assigned Outcome: High
Assigned Outcome: Low
Session One: Last 20 Trials
Session Two: 20 Trials

Appendix

QUESTIONNAIRE

You do not need to answer questions that make you uncomfortable or that you do not want to answer.

1. Do you have experience playing board games that involve rolling of dice? (i.e. Yahtzee, Monopoly, Life, Sorry, etc)

☐ Yes ☐ No

If yes please complete chart below:

Game	Number of times played	Last time played

2. Do you have experience playing card games? (i.e. poker, euchre, gin, bridge, crazy eights etc.)

☐ Yes ☐ No

If yes please complete chart below:

Game	Number of times played	Last time played	Skill level (beg/int./adv)

3. Do you have experience with lottery tickets? (i.e. scratch to win tickets, draws, etc.)

☐ Yes ☐ No

If yes, please complete chart below:

Type of ticket	Number of times per month	Number of years

4. Have you ever gambled at a casino?

☐ Yes ☐ No

If yes please complete chart below:

Type (i.e. card game, slot machine etc)	Number of times per month	Number of years	Skill level (beg/int./adv)

5. Do you prefer to watch or actively participate in games of chance? ___________

Why? ____

____

The following is a list of statements related to gambling. Please read each statement carefully and indicate how much you agree or disagree with it by circling the appropriate number. Please do not take too much time in responding to the items:

6. I consider myself to be a reasonably adept gambler.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

7. Some gambling games (e.g., slot machines) are more likely to pay out than others.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

8. The longer a slot machine has gone without paying out a large sum of money, the more likely are the chances that that it will pay out in the very near future.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

9. It is a good idea for people to purposely avoid playing on slot machines that have recently paid out a lot of money.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

10. I believe that there is such a thing as winning and losing streaks.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

11. After a long string of wins on a slot machine, the chances of losing become greater.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

12. I am often willing to take risks.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

13. After a long string of losses on a slot machine, the chances of people winning become greater.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

14. There is often a hidden pattern in most sequences of supposedly random events.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

15. A long string of wins or losses on a slot machine will have no influence on future wins or losses

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

16. If you experience a losing streak while gambling, the thought that a win has to be coming soon should keep people going.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

17. If someone tosses a coin five times and the first four tosses come up heads, you think that the fifth toss will be more likely to be tails than heads.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

18. There are certain strategies that one should use when playing a slot machine (e.g., betting all remaining credits at once) that will help that person win.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

19. If others are winning in a gambling game, I feel that my turn is coming too.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

20. Sometimes, it's a good idea to keep gambling if you get a strong feeling that you are about to win.

1 Don't agree at all	2	3	4	5	6	7 Strongly agree

21. The lottery numbers 1, 2, 3, 4, 5, 6 are less likely to win a jackpot than the lottery numbers 6, 11, 8, 46, 12, 13.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

22. I feel that I can influence the outcome of a roll of the dice by how I hold the dice before throwing them.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

23. I would feel more confident of winning a lottery if I picked the numbers myself than if the computer picked them for me.

1	2	3	4	5	6	7
Don't agree at all						Strongly agree

The following is a list of questions regarding the experimental task you just completed.

24. In this task, was there a strategy that you used to influence the outcome of the dice- roll?

☐ Yes ☐ No

If yes, please explain: ____
____
____

25. Did you think your performance on one trial will affect the outcome of that trial?

☐ Yes ☐ No

Why or why not? ____

26. Would your performance be affected if you were distracted?

☐ Yes ☐ No

Why? ____

27. Do you think your performance on this task could improve with practice?

☐ Yes ☐ No

Why or why not? ____

____