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Judgment and Decision Making, Vol. 10, No. 5, September 2015, pp. 503–510

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Abstract

In motor lotteries the probability of success is inherent in a person's ability to make a speeded pointing movement. By contrast, in traditional economic lotteries, the probability of success is explicitly stated. Decision making with economic lotteries has revealed many violations of rational decision making models. However, with motor lotteries people's performance is often near optimal, and is well described by statistical decision theory. We report the results of an experiment testing whether motor planning decisions exhibit the attraction effect, a well-known axiomatic violation of some rational decision models. The effect occurs when changing the composition of a choice set alters preferences between its members. We provide the first demonstration that people do exhibit the attraction effect when choosing between motor lotteries. We also found that people exhibited a similar sized attraction effect in motor and traditional economic paradigms. People's near-optimal performance with motor lotteries is characterized by the efficiency of their decisions. In attraction effect experiments performance is instead characterized by the violation of an axiom. We discuss the extent that axiomatic and efficiency measures can provide insight in assessing the rationality of decision making.

Keywords: attraction effect, motor planning, preference reversals, optimality.

1 Introduction

Decisions occur at multiple levels in the cognitive hierarchy. For example, a higher-level decision might be between competing pension investments. A lower-level decision, on the other hand, might be between different hand trajectories available in order to pick up a glass. As a consequence, different methods have been developed to allow researchers to study decisions across the hierarchy.

On first inspection, some methods, used at some levels in the hierarchy, appear to result in better decisions than others. For example, a recently developed approach involves asking subjects to hit a touch-screen displaying reward and penalty zones (Trommershäuser, Maloney, & Landy, 2008). Subjects in these paradigms cannot be sure where they will make contact because there is a severe time limit forcing them to make a rapid movement. Given this uncertainty, the decision they must make is where to aim in order to maximize reward. Research using this method has revealed that, of all the possible aim points, people select one that is close to maximizing reward. It is possible to argue therefore, that in these motor lotteries people make near optimal decisions given the uncertainty induced by noise in their motor system.

In addition to selecting the optimal aim point within a configuration of penalty and gain zones, it has been shown that subjects can select between alternative configurations according to which has the highest expected gain (Trommershäuser, Landy, & Maloney, 2006). Subjects were presented with two alternative configurations of gain and penalty zones and were instructed to choose one. Subjects reliably chose the configuration that contained the most valuable aim point. This suggests that not only do people choose the aim point that maximizes their gain, but also that this ability also translates into a higher level task of choosing between different configurations of motor lotteries.

A more traditional paradigm in decision making research, which has been used to probe higher level decision making, involves explicitly described lotteries of the form "a 50% chance of $10". These traditional lottery selection tasks have been used to highlight a number of ways in which human decision making apparently violates rational models, indicating that our decision making is not always optimal (Huber, Payne, & Puto, 1982; Tversky & Kahneman, 1981, 1992).

The contrast in performance (with respect to what is optimal) between motor and traditional paradigms might mean that people are simply better decision makers when it comes to motor tasks. There is, however, recent evidence that this is not be the case. Wu, Delgado, and Maloney (2009) looked for a violation of the independence axiom (i.e., the common consequence effect Kahneman & Tversky, 1979) in motor

Our thanks to Jon Baron and two anonymous reviewers whose insightful comments have improved the manuscript. The UK Economic and Social Research Council (ESRC) funded GF's postgraduate study. PAW, WED, & AH are funded by an ESRC transformative research grant ES/L00321X/1. GF was also part supported by a grant from the Isaac Newton Trust / Wellcome Trust ISSF / University of Cambridge Joint Research Grants Scheme.

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planning decisions. In these motor planning decisions subjects are first trained in their own motor noise while attempting to hit a target. They are then presented with alternative hypothetical targets which have associated rewards. Crucially, these motor lotteries can be made to be mathematically equivalent to traditional lotteries. Having established a fair basis for comparison of the two paradigms, Wu et al. (2009) found that the independence axiom was violated in both types of decision.

Jarvstad, Hahn, Rushton, and Warren (2013) found further evidence of similarities, rather than differences, between motor and traditional decision making. They argue that the apparent difference in optimality is partly a product of using different performance metrics. The performance metric in motor tasks is often based on efficiency, i.e., how much of the maximum possible gain people achieve. This is a sensible metric to use because there are many different aim points that have very different expected values. However, the performance metric in traditional decision making tasks is often based on compliance with axioms required by rational models, such as the independence axiom mentioned above. Given these different ways of assessing performance, it is not straightforward to compare existing motor and traditional decision making experiments. Jarvstad et al. (2013) compared motor and traditional decision making whilst using the same efficiency metric to assess performance in each. Subjects were presented with decisions between gambles that varied in expected value. The efficiency of their performance compared to that of a theoretical optimal decision maker, was approximately 92% in both the motor and traditional economic paradigms. There was no significant difference between motor and traditional decision making when assessed with an efficiency metric.

In the present study we further probe the consistency of motor planning and traditional economic decision making by testing for the attraction effect. We have used a standard motor lottery planning paradigm in which people make decisions between different potential movements. As in the existing literature using this paradigm (Jarvstad et al., 2013; Wu et al., 2009; Zhang, Daw, & Maloney, 2015), subjects are trained on their motor noise in a pointing task, and then given choices between alternatives that closely represent the training trials, but without the performing the movement. The objective is to understand people's movement planning based on their internal representation of their motor error. We examine whether the attraction effect can influence this planning process.

The attraction effect is a further example of a sub-optimal decision making phenomenon revealed by the violation of an axiom (Huber et al., 1982). Specifically, this effect violates the axioms of independence from irrelevant alternatives (IIA Luce, 1959) and regularity. These axioms are part of many rational value-maximizing models, and require that decision makers assess each alternative independently of the other alternatives. The attraction effect suggests that people do not do this, since adding an alternative to a choice set appears to change preferences between the original members. The effect has therefore had a major influence on decision making theory and is frequently cited as evidence that rational value-maximizing models do not describe human decision making (Ariely & Wallsten, 1995; Heath & Chatterjee, 1991; Huber et al., 1982; Louie, Khaw, & Glimcher, 2013; Ratneshwar, Shocker, & Stewart, 1987; Roe, Busemeyer, & Townsend, 2001; Sen, 1998; Simonson, 1989; Tsetsos, Usher, & Chater, 2010; Tversky & Simonson, 1993; Usher & McClelland, 2004).

To elicit the attraction effect, choices are described on two attributes that trade-off, for instance acceleration and fuel-efficiency in cars. Consider a person torn between car A with good acceleration, but low fuel-efficiency, and car B with poor acceleration, but high fuel-efficiency. The attraction effect tells us that offering an additional third option which is similar to A but slightly worse on both attributes (or the same on one attribute and worse on the other) would bias a typical decision maker toward choosing car A over car B.

The effect has been demonstrated in a variety of product categories (Huber et al., 1982), including lotteries (Herne, 1999; Soltani, De Martino, & Camerer, 2012; Wedell, 1991). For lotteries, the two attributes that trade-off are probability and value. Figure 1 shows a configuration in which the attraction effect would be expected to occur. The safe lottery ("safe" because it has higher probability of success) is called the target because it strictly dominates the decoy on both attributes, making it more likely to be chosen than the risky lottery ("risky" because it has lower probability of success), called the competitor. Note that the competitor is better than the decoy only on one attribute. The attraction effect is an extremely robust phenomenon, which as well as being shown across a wide range of products, also occurs across a variety of species, including birds, honeybees (Shafir, Waite, & Smith, 2002) and even slime mould (Latty & Beekman, 2011). Contextual preference reversals have also been shown in lower level perceptual decisions, Trueblood, Brown, Heathcote, and Busemeyer (2013) found the attraction effect in deciding which of three rectangles had the larger area.

A critical feature of attraction effect experiments is that subjects must decide between target and competitor alternatives that are designed to be approximately equally attractive. In the case of choices between lotteries, these will have identical or very similar expected values. This manipulation exists so that subjects are maximally uncertain as to which alternative they prefer. This aspect of attraction effect experiments means that the efficiency metric used to determine near-optimality in motor tasks is not suitable. In attraction effect experiments the two viable options (the target and competitor) are equally efficient.

The experiments conducted by Trommershäuser et al. (2006) appear to show that people choose between different configurations according to which configuration contains the most valuable aim point. This suggests that in the evaluation and planning of different motor lotteries, people are able to choose according to which will maximize value. However, as in most motor paradigms these findings relate to choices between configurations that vary in expected value and therefore an efficiency metric is suitable.

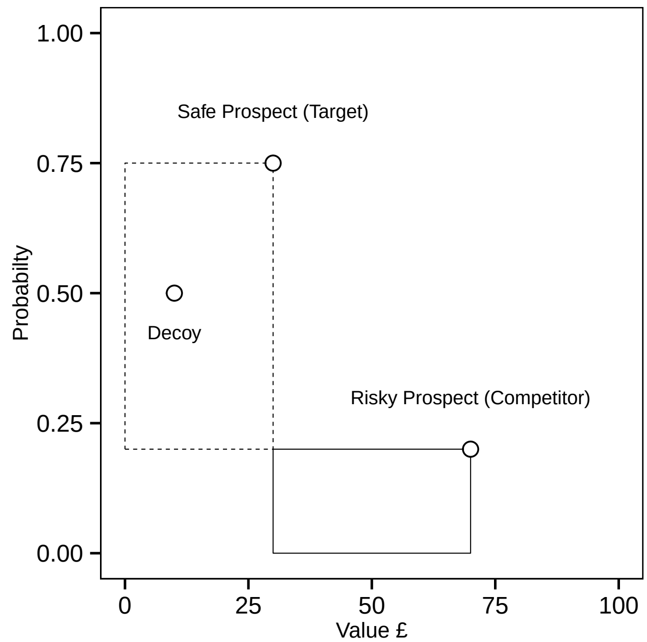
As argued by Jarvstad et al. (2013), it may be necessary to use designs with alternatives that do not vary in expected value in order to elicit sub-optimal decision making phenomena. In a previous experiment using perceptual and explicit representations of probability, we have found that introducing a difference in expected value between lotteries can eliminate the attraction effect. (Farmer et al., submitted). It is possible therefore, that it is the nature of the pay-off environment, and the performance measure used, that drives whether many sub-optimal phenomena will be elicited. We expect that a motor paradigm *can* be used to elicit the attraction effect, if the available alternatives are approximately equally valuable. We will suggest a potentially unifying account of the different findings that emerge from efficiency and axiomatic measures of performance. It may be that axiomatic violations occur precisely when there is the least consequence in terms of efficiency, and that these axiomatic violations reflect an attempt to resolve residual uncertainty left over by a value-maximizing decision process.

In the experiment reported here, we test for the attraction effect in motor planning decisions. Using the Wu et al. (2009) method we constructed choice sets of motor lotteries, and mathematically equivalent traditional lotteries as a control. If the attraction effect occurs, then, as well as being the first demonstration of this phenomenon in motor planning decisions, it will provide further evidence that the discrepancy in performance between motor and traditional higher-level decision making may be unfounded.

2 Method

Our method of creating motor lotteries that are mathematically equivalent to explicitly described lotteries, is adapted from Wu et al. (2009); Wu, Delgado, and Maloney (2011). This involves measuring a subject's variance over repeated attempts to hit a target. This variance is used to determine the width of target necessary to achieve a chosen probability that it will be hit. Subjects can then be offered choices between targets of differing widths equivalent to offering them choices between lotteries of varying probability.

Figure 1: The attraction effect. If a decoy lottery is added to the dashed area, the safe lottery will gain choice share from the risky lottery. If the decoy were instead added to the solid area, then the risky lottery would be the target, and would gain choice share from the safe lottery—now the competitor.



2.1 Subjects

Sixty one (eight male) undergraduate subjects with a mean age of 20 ($SD = 2$) were recruited from the University of Manchester. Subjects received course credit for taking part in the experiment, and attended for one session of approximately 40 minutes.

2.2 Materials

A 19 inch touch-screen at a resolution of 1280 by 1024 pixels was used throughout the experiment. In the choice phase subjects responded by pressing 1, 2 or 3 on the numeric keypad of a standard Windows keyboard. The experiment was created in the Python programming language and run on a Microsoft Windows 7 PC.

2.3 Design

We used a 3 context (target, neutral, competitor) x 2 paradigm (motor, traditional), entirely within subjects design. The attraction effect predicts that the same alternative will be chosen more often when it is a target than when it is neutral or a competitor. An alternative is a target when it dominates a decoy on one attribute, and is equal to, or better than, the decoy on the other attribute. To test for the attraction effect, we constructed a safe lottery (higher probability of success) which had a value of £20 and a success probability of 70%. This was offered alongside a risky lottery (lower probability of success) which had a value of £75 and a success probability of 30%. This pair of lotteries was presented nine times with each as the target and another nine times with no decoy present (neutral). This resulted in 27 trials per paradigm. This design allowed us to calculate a choice rate for each lottery in each context i.e., the proportion of times it was chosen for each placement of the decoy.

Rather than present identical choices nine times, the values and probabilities were jittered such that values were either £19, £20 or, £21 and probabilities were either .69, .70 or .71. This resulted in nine safe lotteries with a mean value of .7(£20). The same procedure was applied to the risky lottery and the decoy lotteries.

The two paradigm levels (motor and traditional) differed only in the way that the probability of the lottery was displayed. In the traditional paradigm, the value and probability of a lottery were displayed on-screen in numerical format (see Figure 2). In the motor paradigm the probability of the lottery corresponded to varying widths of targets (Figure 3). In both paradigms the hypothetical amount to be won was displayed in the form ‘£20’.

As in previous studies with rapid pointing tasks (reviewed in Trommershäuser et al., 2008) a time limit meant that subjects could not be sure of hitting the target. Our subjects completed a training phase prior to the choice phase in which we recorded their hit points to recover a distribution of their accuracy around a target center. This distribution of subjects’ hit points was then used to create individualized stimuli in the choice phase. This allowed us to control the probability of success for each subject by varying the width of the targets they were presented with.

A pilot study was conducted to determine a value that would make the risky lottery subjectively equivalent to the safe lottery. Decoys were always .15 less likely to win and of £5 less value than their dominating lottery.

2.4 Procedure

2.4.1 Training phase

In the training phase subjects learned their own motor noise in a rapid pointing task. Subjects were instructed to touch a green bar on the left hand side of the screen with the index finger of their dominant hand, after which they had 500 msec to touch a yellow target bar on the right hand side of the screen with the same finger. The target zone was 20 pixels in width and 1025 pixels to right of the of the start bar. The start bar was 50 pixels wide and covered the full height of the display (1024 pixels), as did the target zone.

Subjects completed 100 training trials as described above.

Figure 2: Example stimulus in the traditional condition. Subjects indicated which lottery they would prefer to play.

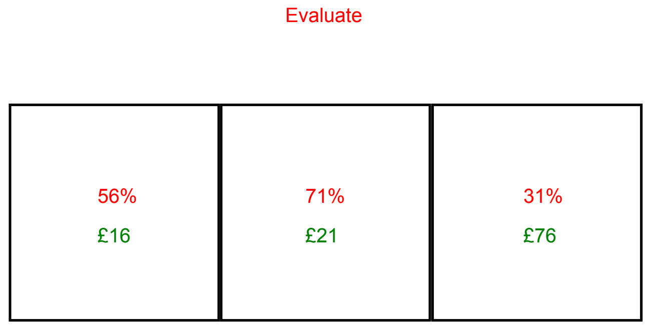
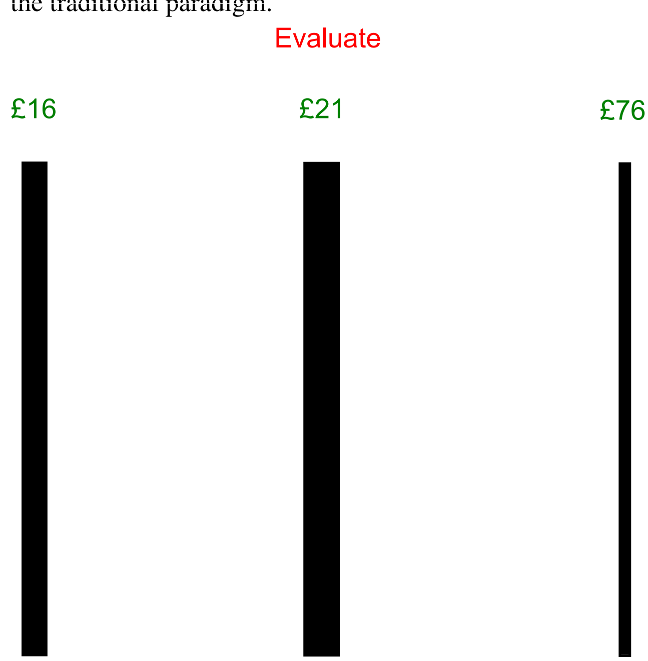


Figure 3: Example stimulus in the motor condition. Subjects were told to indicate which of the three lotteries they would prefer. The width of the targets (black bars) was manipulated to achieve probabilities identical to those used in the traditional paradigm.



Subjects were not informed that they would be making decisions between different target widths in the subsequent choice phase. If subjects successfully hit the target within the time limit the word “Hit” would appear in green. If they were within the time limit but missed, the word “Miss” was displayed in orange. If they exceeded the time limit, the message ‘Too slow’ was displayed in red and a warning sound was played.

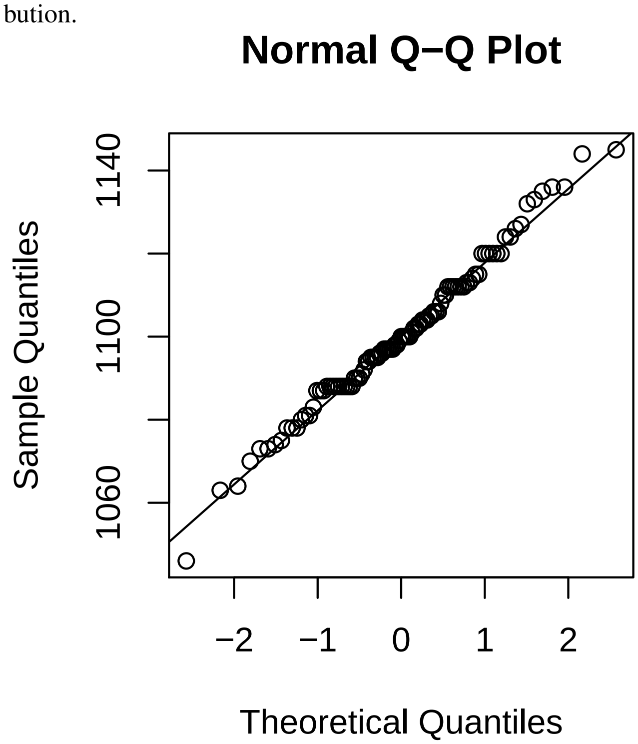
2.4.2 Choice phase

In the choice phase subjects saw three lotteries presented on the screen and a message stating "Evaluate" above them (see figure 3). Subjects were instructed to press the space bar when they were ready to indicate their choice. The message would then change to "Choose", and one of three lotteries would disappear. Subjects had to choose between the remaining two lotteries by pressing the appropriate number on the keyboard. In the majority of trials the decoy was removed when the space bar was pressed. However, in some trials the decoy remained and either the target or competitor lotteries were removed. These trials were excluded from the analysis but were included in the stimuli to encourage subjects to evaluate all the lotteries. Subjects indicated their preferred lottery using the numeric keypad, 1 for the left most lottery in the display, 2 for the middle lottery and 3 for the right-most lottery. The 54 trials (27 motor and 27 traditional) were presented in random order such that the motor and traditional trials were mixed together. Each subject experienced a different random order. The position of each alternative on the screen was also randomized.

Subjects had only two seconds to make their response after pressing the space bar. If they exceeded this time limit, "Too slow" was displayed and the trial was discarded from the analysis. The process of evaluating, removing an option, and choosing under a time constraint was adapted from Soltani et al. (2012) with the purpose of forcing subjects to take all three alternatives into consideration when making their choice. Since the subjects experienced some trials (not analyzed) on which the target is removed and the decoy remained they had to take the decoy into account as a viable option.

In the choice phase subjects were asked to indicate which lottery they would prefer, but they did not go on to play the lottery, nor receive any other type of feedback. For the motor lottery choices subjects were instructed to imagine that their chosen option would be played out in a manner identical to the motor training phase. If they successfully hit the target they would win the amount shown, otherwise they would win nothing.

Figure 5: Quantile-quantile plot of a subject's hit points during the training phase. The y axis shows the location in pixels of the hit point. The center of the target was at 1100 pixels. The hit points are well described by a normal distribution.



3 Results

The left panel in Figure 4 shows the results for the traditional paradigm. The safe lottery was chosen more often when it was the target than when it was the competitor. The neutral bar in the figure indicates the rate that the safe lottery was chosen when there was no decoy present. Overall in the traditional paradigm, the safe lottery was chosen in 70% of trials when it was the target, and in 57% of trials when it was the competitor. The preference reversal rate was therefore 13%, and is consistent with other studies of the attraction effect in choices between lotteries (Soltani et al., 2012; Wedell, 1991).

Analysis of the motor training phase showed that the distribution of subjects' hit points was well described by a normal distribution centered on the target (see Figure 5). Table 1 shows the change in the hit point, the standard deviation of the hit point and the duration of a pointing movement in each quarter of the training phase. From the outset, subjects' aim points were centered on the middle of the target, which was located at 1100 pixels. As the training progressed subjects' motor variability reduced slightly from 21 to 18 pixels.

The right panel in Figure 4 shows the rate the safe lottery was chosen when it was the target and the rate it was chosen when it was the competitor, in the motor condition. Subjects chose the safe lottery in 73% of trials when it was the target, and in 62% of trials when it was the competitor. Consequently, the motor preference reversal rate was 11%.

Data were transformed by taking the arcsine of the square root of the choice proportions. A 2 (paradigm) x 3 (context) repeated measures ANOVA revealed a significant effect of context $F(1.75, 105.18) = 21.73, p < .001, \eta_p^2 = .27)$, but not of paradigm $p = .26$. There was no significant interaction $p = .63$. Bonferroni corrected post hoc comparisons

Figure 4: Proportion of trials the same lottery was chosen according to the context in which it was presented. The left panel shows that, for the traditional condition, the safe lottery was chosen more often when it was presented as a target, consistent with the attraction effect. The right panel shows the same analysis for the motor condition, subjects also chose motor lotteries more often when they were targets than when they were competitors. Error bars are standard error

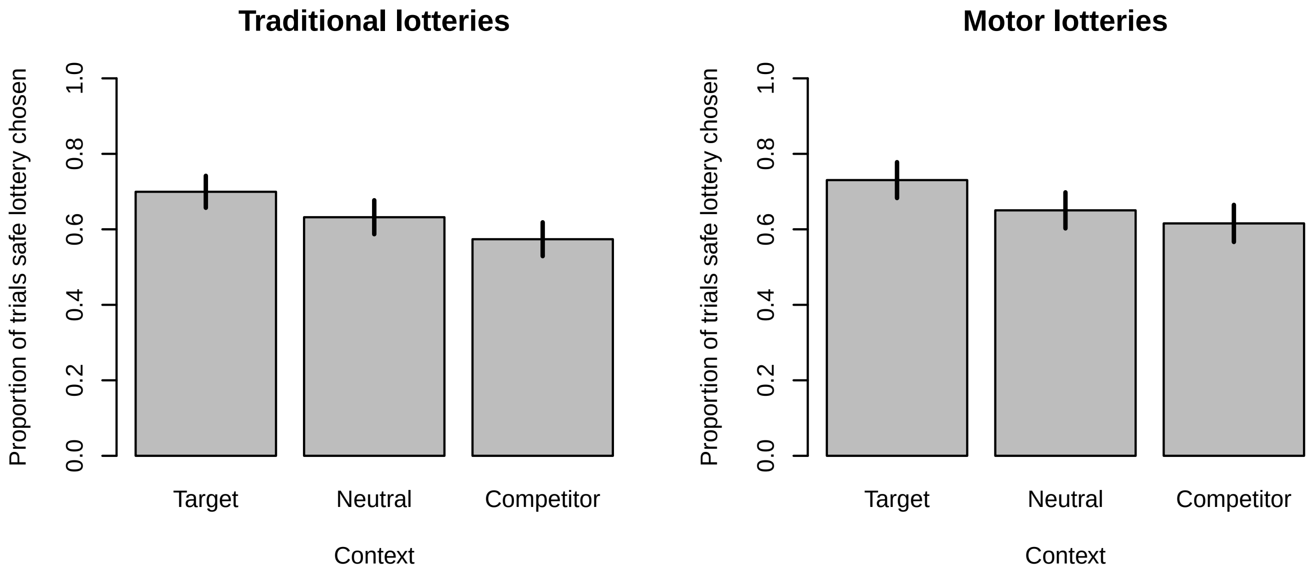


Table 1: Motor training summary statistics. Values show are the median statistic across all subjects from the motor training session.

	Hit point	Standard Deviation	Duration (ms)
Block 1	1099	21	407
Block 2	1099	19	430
Block 3	1098	19	434
Block 4	1099	18	437

revealed that all three levels of the context IV (target, neutral and competitor) were significantly different from one another.

4 Discussion

Our results provide evidence that changing the composition of a choice set affects how motor lotteries are evaluated. More specifically, subjects exhibited the attraction effect by selecting a lottery more often when it dominated a decoy than when it did not. This finding adds to the body of literature showing that the attraction effect is pervasive across tasks and organisms. These data provide the first evidence of contextual preference reversals in the evaluation of motor lotteries.

The presence of the attraction effect in the evaluation of motor lotteries lends support to previous findings by Jarvstad et al. (2013) and Wu et al. (2009). Whilst Jarvstad et al. (2013) found that choices in motor and traditional lotteries were equally efficient, Wu et al. (2009) found that violation of the independence axiom in traditional lotteries can be elicited in mathematically equivalent motor lotteries. Taken together, this previous research suggests that when the same performance metrics are used, the optimality of decision making does not differ between motor and traditional paradigms. This conclusion is strongly supported by the results we report here. We found that choice sets used to elicit the attraction effect in traditional lotteries, also work in equivalent motor lotteries.

Decision making that violates axioms required by rational models is often exhibited in choice sets where there is little consequence to the decision maker of the violation; the bias or irrationality is a logical one, but not necessarily a practical one (Hahn & Harris, 2014, see also Dunwoody, 2009 for a similar distinction between coherence and correspondence in decision making). Whilst decision making in motor lotteries may appear optimal, that is potentially because the measure of performance is essentially a practical one. Our results suggest that the optimality or otherwise of decision making is not dependent on the paradigm, but on how we define and measure optimality. In choice sets with alternatives that vary in efficiency, and where efficiency is used as the performance metric, both motor and traditional paradigms can be used to elicit near optimal decision making. In choice sets where alternatives have very similar expected values, and performance is measured by conformity with axioms, both motor and traditional paradigms can be used to elicit apparently irrational decision making.

One question that remains to be answered is why contextual effects, such as the attraction effect, occur in choices that are approximately equally attractive? Existing explanations of the attraction effect focus on the neural and algorithmic processes which might produce the effect (Bhatia, 2013; Noguchi & Stewart, 2014; Roe et al., 2001; Simonson, 1989; Stewart, 2009; Usher & McClelland, 2004). We suggest a new interpretation that has the potential to unify the findings from different performance metrics. A value-maximizing decision making process is least useful when the alternatives on offer have the same value. Given a situation in which the available alternatives appear to have roughly the same value (as the attraction effect choice sets are by design) additional information can be gleaned from the composition of the choice set. Consider a set of target, decoy and competitor lotteries. All appear to have similar expected values, but given that the target must be greater than the decoy, there is also an increased likelihood that it will be better than then competitor. Of the six possible utility rankings among the alternatives, only those in which the target exceeds the decoy are permitted. In two-thirds of this subset of rankings the target has higher expected value than the competitor. The only prerequisite for this information to be useful is that the decision maker cannot calculate expected value with perfect accuracy (Howes et al., submitted).

The attraction effect may be an entirely rational use of contextual information in choice sets where the available alternatives are approximately equally valuable. One only needs to assume noise in the calculation of expected value for this to be true. This raises the intriguing possibility that axiomatic violations of rationality are the result of the decision maker trying to exceed what value maximization alone can achieve. Of course, in choice sets where the alternatives are very variable, the process of value maximization exceeds any subtle influence of context. The rationality we attribute to the attraction effect is computational (Howes, Lewis, & Vera, 2009; Lewis, Howes, & Singh, 2014) rather than normative. To be clear, a person capable of making perfect expected value calculations should not exhibit the attraction effect. However, a person with a noisy ability to estimate expected value, can reduce the noise by taking into account the dominance of the target over the decoy.

Axiomatic violations such as the attraction effect are typically interpreted as evidence that value maximizing models fail to describe human decision making. The presence of the attraction effect in motor lotteries suggests an alternative interpretation in which these effects reflect a decision maker's efforts to exceed what a value maximizing model would achieve in choice sets where alternatives are similarly valued. Some axiomatic violations may not be irrational, they may exist to resolve residual uncertainty that cannot be resolved by pure value-maximization. In that sense, they are entirely rational *given* that uncertainty, that is, they are computationally rational because they optimize reward given the constraints that bound cognition. Further work should focus on testing this insight for other axiomatic violations.

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