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I control therefore I do: Judgments of agency influence action selection

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ABSTRACT

Our sense of being agents, that is of willingly controlling both our own bodies and the external environment is ubiquitous if thin. Empirical and theoretical work on this 'sense of agency' has documented motivational, cognitive and neural influences on implicit (out of awareness) and explicit (conscious) judgments of agency. For example, fluency of action selection processes has been recently shown to affect judgments of one's degree of control over an external event. However, it is an open question whether and how such judgments of agency act as input to other processes. In this study we demonstrate that the opposite relationship between action selection and judgment of agency also exists. Specifically, we show that manipulating one's objective control over the environment influences both the speed and the frequency of performing an action associated with that control. This pattern bears a striking resemblance to the effect that tangible rewards have on action selection and suggests that positive control feedback is rewarding to the organism, consequently affecting action selection. If further corroborated this 'reward from control' may explain everyday addictions such as prolonged engagement in arcade games and pathological behaviors, such as stereotypy.

> "…we may plausibly argue that a capacity to be reinforced by any feedback from the environment would be biologically advantageous, since it would prepare the organism to manipulate the environment successfully…"
>
> [B.F. Skinner, 1953, p. 83]

1. Introduction

Millions around the world invest their limited time and money in what at first blush seem to be rather futile activities. Take for example the recent success of 'Candy Crush Saga', a *free* Facebook arcade app that had people paying close to a million dollars *per day* for game related options (Top grossing iOS games, June 10th 2014). What kept so many people playing and paying? A digression into the mechanisms responsible for generating our 'sense of agency' may give at least a partial answer to this question.

1.1. Action selection affects judgment of agency

Research on the 'sense of agency', that is of willingly controlling both our own bodies and the external environment has focused almost exclusively on the underlying situational factors and neurocognitive mechanisms that are responsible for generating and affecting this sense (for recent reviews see Haggard & Eitam, in press). Libet, Gleason, Wright, and Pearl's (1983) seminal work had suggested that a causal link exists between

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the motor preparation related 'readiness potential' and one's feeling of the 'urge to act'. Others have refined this initial finding showing that it is the more advanced stages of selection (selection of effector; e.g., right hand) that are related to the feeling that one is about to act (Fried et al., 1991; Haggard & Eimer, 1999). Even more recently, Chambon and Haggard (2012) have supplied evidence for a predictive (in contrast to the 'postdictive' [e.g., comparator based] or reconstructive [e.g., Wegner & Wheatley, 1999]) account for another aspect of the sense of agency—the mind's judgment of being the source of a change in the environment. Specifically, they showed that fluency in action selection—manipulated by subliminally priming congruent or incongruent upcoming actions—increases the sense of control over a non-contingent outcome.

Although our understanding of the sense (or rather—senses) of agency is far from complete, an alternative direction of research has been all but neglected; namely, whether and how the judgment of agency acts as input to other processes affecting further action.

1.2. Judgment of agency affects action selection

To be clear, the idea that agency (vs. the pursuit of outcomes) motivates has been previously suggested by theorists of different traditions (e.g., Deci & Ryan, 1987; Higgins, 2012; Skinner, 1953; White, 1959); but although these proposals are indeed instructive, their conceptualization of agency varies dramatically (e.g., from 'managing what happens' to 'self-determination') and their mechanistic specification is generally minimal. As such, they are not easily linked to the last two decades of theorizing and empirical results on the far more narrowly defined sense of agency. To bridge this gap we adopt the narrow definition of agency used in the rapidly growing corpus of research on the sense of agency; specifically, implicit (unintentional and out of awareness) and explicit (intentional and aware) judgment of willingly controlling both our own bodies and the external environment.

The mind's ongoing (implicit or explicit) registration of changes in the environment as self (or externally)-caused (i.e., judgments of agency) are highly functional for the organism. For instance, the mind's positive judgment of agency over action effect enables the organism to adjust to a dynamic environment and behave in a goal directed manner (Hommel & Elsner, 2009; Elsner & Hommel, 2001). Hence, the mind-brain may have evolved to reinforce the discovery and prioritization of actions that lead to control over the environment (Redgrave & Gurney, 2006; Redgrave, Gurney, & Reynolds, 2008). In this paper we test one outcome of such a hypothetical mechanism—namely, how the mind's judgments of agency over trivial perceptual effects influence both the frequency and speed of re-selecting control-related actions.

Two extant studies lend direct support to the prediction that valance-neutral own-action-effects do in fact increase motivation (Eitam, Kennedy, & Higgins, 2013; Stephens, 1934) but unfortunately, in both the mere exercise of control was not clearly dissociated from information about obtaining desired outcomes (e.g., successful task performance). As such, even the simple question of whether mere agency motivates *in and of itself* is still wide open.

1.3. Judgment of agency affects action selection: control as reward

Recent neuroscientific findings support the proposal that judgment of agency could affect observed motivation (e.g., frequency and speed of behavior) by influencing the value of actions repeatedly associated with decisions of control. The brain's 'reward system' represents (among other functions) the predicted reward value of an action (for a review see, Balleine, Delgado, & Hikosaka, 2007). Predicted values are then utilized by the brain to produce adaptive behavior by biasing response selection towards the response with the highest value (Redgrave, Prescott, & Gurney, 1999). Behaviorally, response options with higher predicted outcome value (e.g., more food or water) are selected more frequently (Samejima, Ueda, Doya, & Kimura, 2005) and more rapidly (Brown & Bowman, 1995) than other, lower value, response options.

But which responses are rewarded by human brains? Consistent with the overwhelming behavioral evidence that people are motivated by positive outcomes it is relatively well established that the human reward system responds to primary (e.g., water; Samejima et al., 2005) and secondary reinforcers (e.g., money; Pessiglione et al., 2007). It is less well known that it also responds to events signifying actual (Behne, Scheich, & Brechmann, 2008; see also, Bednark & Franz, 2014) or potential (Leotti & Delgado, 2011; Tricomi, Delgado, & Fiez, 2004) control over the environment.

Integrating these lines of evidence, we recently proposed that above and beyond an action's predicted outcome value, the mind/brain *selects responses* on the basis of their predicted control value; hence, actions associated with positive judgments of agency (e.g., *encoded as more likely to have an effect*) would be selected more rapidly and more frequently, just as those associated with a greater predicted outcome value (Karsh & Eitam, in press).

1.4. Judgment of agency affects action selection: implicit and explicit judgment of agency and levels of action selection

It has been suggested that the process of action selection differs at various levels of abstraction (Badre, Kayser, & D'Esposito, 2010). Specifically, selection at the motor level of actions (e.g., which muscles to move) is driven by low-level sensory information and is inaccessible to conscious awareness. On the other hand, selection among more abstract action representations (e.g., "should I use my left or the right hand to open the door?") is accessible to conscious awareness (Libet et al., 1983) and is argued to involve volition (James, 1980).

Within the proposed framework and consistent with recent developments modeling the sense of agency (e.g., Moore, Middleton, Haggard, & Fletcher, 2012; Synofzik, Vosgerau, & Newen, 2008), the implicit sense of agency is suggested to emerge from internal models in the motor control system. Implicit judgements of agency are sensitive to simple sensory feedback about action effects (see also, Haggard & Eimer, 1999; Redgrave & Gurney, 2006) and a limited number of control parameters (e.g., temporal contingency; Blakemore, Frith, & Wolpert, 1999; Haggard, Clark, & Kalogeras, 2002); accordingly, implicit judgements of agency may affect action selection at lower levels (e.g., motor). On the other hand, an explicit judgment of agency is influenced by one's perceptions and beliefs (Elsner & Hommel, 2001; Wegner & Wheatley, 1999) and may affect higher levels of action selection (e.g., "which finger to respond with?"). As mentioned above, such a framework would be consistent with previous (e.g., comparator; Blakemore & Frith, 2003; Blakemore, Wolpert, & Frith, 1998; Blakemore et al., 1999; Wolpert & Flanagan, 2001) and current (e.g., Synofzik et al., 2008) models relating the sense of agency and action selection.

To recapitulate, our primary goal for the current study was to obtain the first direct evidence that positive judgments of agency over action effects motivate behavior. Our secondary goal was to begin exploring a potential mechanism; namely, an interaction between explicit and implicit judgments of agency and various levels of action selection. In Experiment 1, we tested our main prediction that positive judgment of agency as having own action effects will increase the speed and frequency of action selection. In Experiment 2, we build upon previous research on the sense of agency to test an alternative explanation namely, that the effect motivates behavior because it is perceived as a positive outcome. Finally, across the two experiments we explore how the different levels of response selection are influenced by implicit control parameter (e.g., the temporal contingency of action effect).

2. Experiment 1 – positive judgments of agency increase the speed and frequency of action selection

2.1. Method

2.1.1. Participants

One hundred seventy-four undergraduate students [127 females, Age (M = 24.47, SD = 3.33)] from the University of Haifa participated in the study in exchange for course credit or 20 Shekels (~$6). Twenty-nine [20 females, Age (M = 25.36, SD = 5.05)] students participated in a preliminary experiment and another 145 [107 females, Age (M = 24.29 SD = 2.87)] participated in a follow up experiment.

2.1.2. Stimuli and procedure

Each trial began with the appearance of a red circle ('respond' cue, 53 pixels in diameter) in the center of the game window (dimensions: 413 × 468 pixels). Participants were instructed to voluntarily (Libet et al., 1983) pick and press one of four PC-keyboard keys ('S', 'D', 'H', 'J') each time the red circle appeared. A response could either affect the cueing stimulus by causing it to flash briefly or have no perceptual effect (see Fig. 1 for experimental conditions). Participants were further instructed to take care that the sequence of responses they generate will be as random as possible (i.e., "to avoid any fixed or planned response sequences"). Crucially, whether or not a response generated an effect was uninformative regarding attainment of this outcome.

From trial onset (the appearance of the red circle cue), participants had a 700 ms (ms) long window to freely select and press one of the four keys. Regardless of response speed, SOA (the time that elapsed between the appearance of one response cue to the appearance of the next) was kept constant at 2000 ms. The task included 10 practice trials and 180 experimental trials. No mention of the effects was made in the instructions. In addition, to assess and maintain participants' attention during the task, a blue triangle appeared nine times (on 5% of trials) throughout the experiment instead of the red cue. Participants were instructed to press the "Space" key with their thumb whenever a blue triangle appears.

After completing the task, participants responded to a computerized self-report questionnaire probing their success in attaining the task goal to respond randomly, their intention to cause an effect during the task and their knowledge of the finger-effect contingency mapping. These measures allowed us to assess both participants' explicit judgments' of control and whether they erroneously perceived the effect as indicating success in the task of being random.

Regarding our central goal, if as others have hypothesized, positive control judgment is itself rewarding then behaviorally, this should manifest as faster reaction times and more frequent choice of actions that are reliably associated with a high probability of delivering effects (High Probability condition/key press) compared to when they never deliver such an effect (No Effect condition/key press).

Given the scant research done on judgment of agency and action selection and the large number of possible combinations that can be justified to some degree (e.g., additive or interactive relationships between explicit and implicit judgments of agency; differential effects on the speed ('low level') and frequency ('high level') of responding); our attitude towards our secondary goal – relating the motivating effects of implicit and explicit positive judgment of agency to different levels of action selection – is admittedly, exploratory. Hence we will refrain from making any "a priori" predictions in this direction. This is also how this part of the data should be treated.

An important point should be stressed about the role of the randomness task in this study. The sole purpose of the requirement that participants respond randomly is to enable us to assert relative control over the average probabilities of the response category under conditions of 'free choice'. This control is achieved ironically, exactly because humans generally find the requirement to respond randomly difficult if not impossible and suffice in performing what is called 'probability matching'. Namely, taking care that the overall probabilities of responses are similar (Bar-Hillel & Wagenaar, 1991). Although this tactic would not necessarily generate random sequences (e.g., one could simply respond in a fixed order say '1'–'2'–'3'–'4') the key point is that probability matching in the current (4-option) case entails that the expected probability for each response would be about .25.

Thus, although the actual randomness of participants' behavior is irrelevant to our hypothesis; the instruction to

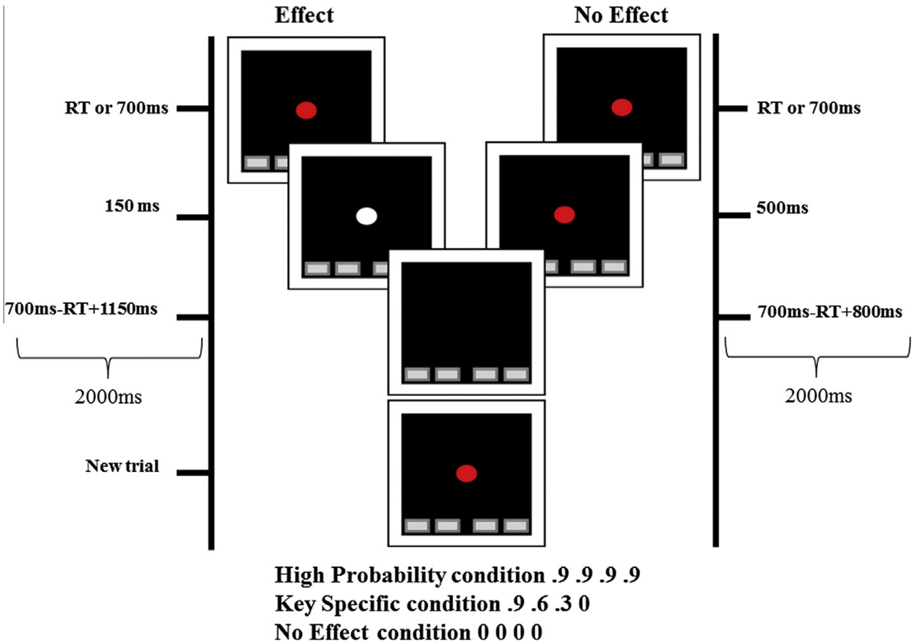

Fig. 1. Experiment 1: a single trial in each of the three between-participant experimental conditions. A relevant response would cause the cue (a red circle) to immediately change its color and disappear with a probability determined according to the experimental condition. In the High Probability Effect condition (henceforth, High Probability condition), each relevant response had a 90% chance to cause such an effect. In the No Effect condition, responses never led to an effect. In the Key Specific Probability Effect condition (henceforth, Key Specific condition), each relevant response was associated with a different probability of delivering an effect (.9, .6, .3, and 0; with allocation to fingers counterbalanced between participants). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

be random allows us to test whether a positive judgment of agency systematically biases response selection by giving us a stable baseline of response proportions (~25% for each of the four options). The existence of such a systematic bias should also lead to another pattern – that participants for whom effect probabilities are identical for all keys (those in the High Probability and No Effect conditions) should select all relevant response keys with similar frequency. This is because response options in these conditions will not be differentially reinforced by positive judgements of agency as they are predicted to be in the Key Specific condition; hence response selection should not be consistently biased towards some responses at the expense of other, making unbiased (“random”) selection easier.

2.2. Results and discussion

2.2.1. ‘Having an effect’ facilitates response selection

Before analyzing the data the following cases were filtered out: when an irrelevant key was pressed, when a response was emitted after the 700 ms response window or was faster than 200 ms, and when response time (RT) deviated by more than two standard deviations from the condition’s mean RT. The total number of trials rejected was 4316/26,100 (16.5%)[1]. All statistical tests were two-tailed with an alpha of 5% unless indicated otherwise.

As a proxy for speed of action selection, we compared the mean RT of the High Probability condition to that of the No Effect condition (Fig. 2). As predicted, we found that RTs’ were significantly shorter in the High Probability condition ($M = 331.08$, $SD = 34.57$) compared to the No-Effect condition ($M = 355.6$, $SD = 40.56$) [$t_{94} = 3.19$, $SE = 4.02$, $p < .01$, $d = .65$, CI_{95} (9.26, 39.76)]. Importantly, faster RT’s in the High Probability (vs. the No Effect) condition was not an outcome of general attentional engagement with the task (see the Supplemental Materials for the relevant analysis and Fig. S1). Furthermore, also consistent with the hypothesis that positive judgment of agency motivates – within each of three conditions RT was negatively related with the number of ‘effects received’ (High Probability condition, $r = -.56$, $p < .01$; Key Specific condition, $r = -.34$, $p = .01$; Key Specific condition-preliminary, $r = -.57$, $p < .01$).

2.2.2. An ‘effective’ response is more likely to be reselected

To increase statistical power and the accuracy of parameter estimation, the following statistical analyses were conducted on the combined data from a small preliminary experiment ($N = 29$), which included only the Key Specific condition and a follow up study ($N = 145$) that included all three conditions described above. We applied the same filter as above in which invalid responses, responses faster than 200 ms, and ones that deviated more than two standard deviations from a condition’s mean RT were dropped from the analysis (1927\14,040; 13.7% of the trials). The data of a participant who did not follow the instructions

[1] Although a relatively high proportion of trials were filtered out, this filter was necessary for this kind of ‘free choice’ task in order to minimize variability that emerges from both response slips and pre-prepared (“planned”) responses. We apply the same filter to data from all our experiments involving this task.

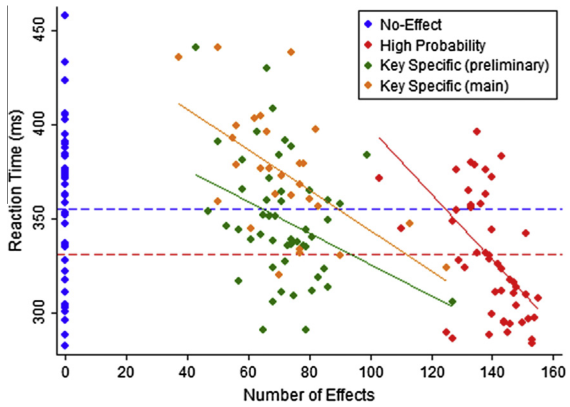

Fig. 2. Experiment 1: reaction time. A scatterplot with fitted regression lines representing participants' RT as a function of the number of effects a participant received. The dashed horizontal lines represent the conditions' mean RT's. The results show that both within and between conditions, responding was sped up as the number of effects received increased.

(failed to use all response keys) were also dropped from the analysis before applying the filter.

In order to test the prediction that responses (i.e. keys) associated with a higher probability of effect will be preferred over those associated with low (or zero) effect probability, we modeled the logarithm of the ratio of the proportion of presses on each of the three keys with non-zero effect probabilities and the proportion of key presses on the key never producing effects using a Dirichlet distribution (see, Buis, Cox, & Jenkins, 2006). In essence the model is equivalent to an omnibus test of whether any of these ratios is statistically different from 0, which is the value that would be expected if all probabilities were not different from the baseline proportion (as log of 1 equals 0). Using the less familiar Dirichlet distribution is necessary as the proportions are bounded between 0 to 1 and as selection of one response category would lower the probability of others being selected. The model was reliable ($\chi^2_3 = 13.91$, $p < .01$), supporting the conclusion that the frequency of responses differed as a function of their probability to generate an effect, in the predicted direction (see Fig. 3a). A planned contrast supports the conclusion that responses associated with a 90% chance to deliver an effect were selected more often ($M = .28$, $SD = .11$) than responses which never delivered an effect ($M = .22$. $SD = .06$) ($Z = 3.55$, $p < .01$). In fact, the only response that was selected reliably more often than baseline (25%) was the response associated with the highest chance (90%) to generate an effect.

After completing the 'randomness task' we asked participants to rate their intention to cause an effect during the task as well as their perceived success in responding randomly (the task goal). This enables us to evaluate whether participants mistakenly perceived the effect as feedback about their success in being random. The scale ranged from 1(very low) to 7(very high). Participants' ratings of the two measures in the critical Key Specific conditions were negatively correlated ($r = -0.22$, $p = .05$), supporting the conclusion that they did not mistakenly perceive the effect as feedback about increased success in the task and hence shaped their behavior after it.

Further support for the effect mere control has on action selection comes from comparing task performance across the three conditions. As stated above, if positive control feedback affects key selection, participants in the Key Specific condition should perform probability matching less well than these of the other two conditions. To test this we created an index that captures deviation from "randomness" (i.e. perfect probability matching) by subtracting the response proportion of each response key from .25 (chance level expected across an infinite sequence of 4 events selected at random) and used the absolute value to calculate the mean deviation from randomness score for each participant. Hence, a lower score indicates greater success in performing the (participants' model of the) focal task (Fig. 3b).

A one-way ANOVA supports the conclusion that the quality of probability matching varied between conditions ($F_{3,\,169} = 3.41$, root $MSE = .05$, $p = .01$). As predicted, a planned contrast supports the conclusion that participants were more successful at "being random" on the two conditions which did not entail a bias for any response; specifically the High Probability and No Effect conditions as compared with the Key Specific condition ($F_{1,\,169} = 9.66$, $p < .01$, $d = .43$). This pattern of results suggests that although participants indeed understood the task goal to be random as probability matching and attempted to meet that goal (as they selected responses at *nearly* identical proportions), having an effect still subtly biased response selection, damaging performance. Specifically, in the Key Specific condition, where some responses conflicted in their effectiveness for control and for outcome (i.e. were task relevant) – at least sometimes control trumped outcome.

2.2.3. The effect of implicit and explicit (self-reported) judgments of agency on action selection

In the background section we briefly mentioned that current work on agency differentiates between implicit and explicit *measures* of agency (Moore et al., 2012) or between *feelings and judgments* of *agency*. To briefly summarize, we hypothesize that an implicit judgment of agency occurs when a prediction of a perceptual event—considered an inherent outcome (but not only) of the mechanisms responsible for motor control (Blakemore & Frith, 2003; Blakemore et al., 1998, 1999; Wolpert & Flanagan, 2001)—is corroborated by the environment. On the other hand, an explicit judgment of agency may be a special case of causal judgment (e.g., Desantis, Roussel, & Waszak, 2011). Here we utilize the above differentiation to test whether implicit and explicit judgments of agency have unique effects on action selection. To attempt to quantify these contributions to action selection, we measured participants' action-effect contingency awareness as a proxy of explicit judgment of agency (see the Supplemental Materials for action-effect contingency awareness scoring scheme). As a proxy for implicit judgments agency (Wolpert & Flanagan, 2001) we used the number of effects a participant received.[2] Finally,

[2] Note that, there is a subtle but crucial distinction between the frequency in which a specific key is selected which is a behavioral measure/operational definition of reinforcement and the number of immediate effects a person receives which we used as a proxy for the number of implicit judgments of agency.

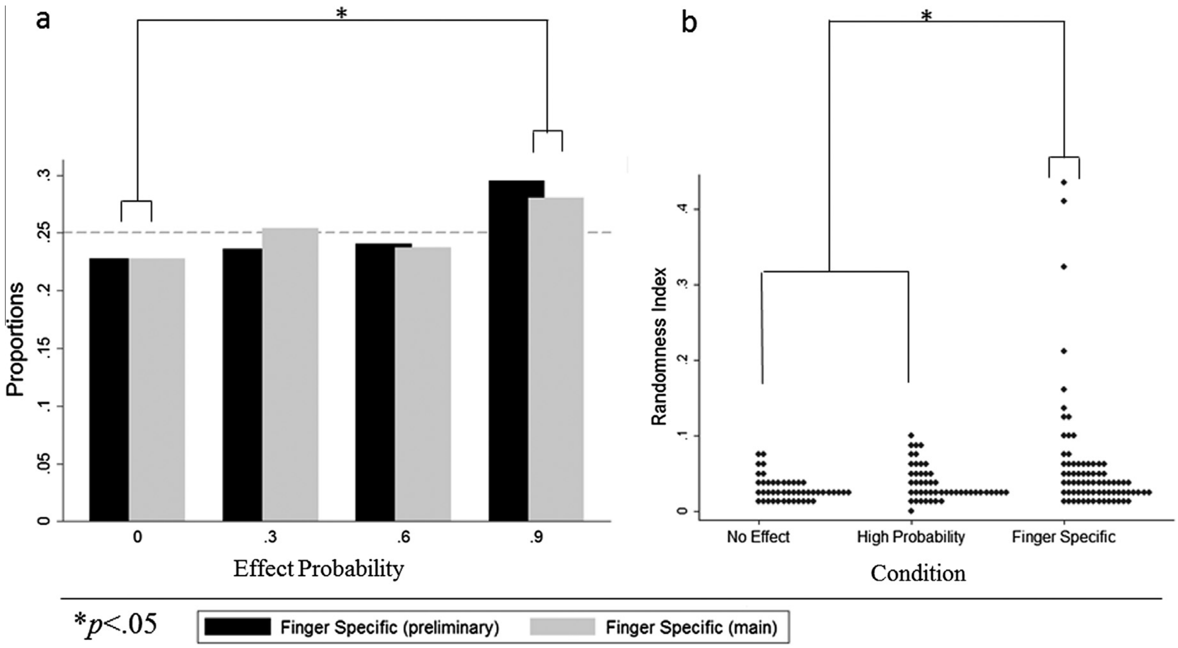

Fig. 3. Experiment 1: response frequency. (a) Proportion of responses by each key-specific effect probability (.9, .6, .3, 0). The dashed horizontal line indicates chance level (.25). Participants' chose the key associated with the highest probability of delivering an effect reliably more often than they chose the key that never delivered one. (b) The "randomness" index, participants' mean absolute deviation from chance (baseline) level shows the cost of the above selection bias for the quality of task performance (i.e. success in probability matching) – participants in the Key Specific condition were less successful at probability matching, which as previous research and our data show is how 'being random' is often implemented by humans.

consistent with previous work (Amalric & Koob, 1987; Brown & Bowman, 1995) we used reaction time (RT) as a sensitive measure of (the speed of) action selection.

As actual action-effect contingencies varied only for the Key Specific conditions, the reaction times of participants from these conditions ($N = 77$) were regressed on the contingency awareness score alone, on the number of effects a participant received alone and simultaneously on both predictors. First, we found that action-effect contingency awareness was linearly and positively related to actual received effects [$F_{1,75} = 17.22$, root $MSE = 2.1$, $p < .01$, $\beta = .43$, CI_{95} (.034, .096)]. The causal direction of this relationship is difficult to determine given the current design; on the one hand, it is consistent with the idea that contingency awareness caused people to 'voluntarily' select the keys that would more probably lead to an effect and hence, is consistent with the notion that explicit positive judgment of agency positively and causally affect action selection. On the other hand, the same statistical relationship is also consistent with the opposite causal direction, namely that the more actual effects a person received the more accurate was her contingency awareness. Although interesting, this latter interpretation does not assign any causal role for an explicit judgment of agency.

The causal direction of the relationship between the two predictors and reaction time (RT; our proxy for speed of action selection) is less ambiguous. When RT was regressed separately on contingency awareness and on the number of effects received, both were positively related with speed of responding (i.e. negatively correlated with RT), explaining substantial portions of the variance in RT, [$F_{1,75} = 10.40$, root $MSE = 32.88$, $p < .01$, $\beta = -.34$, CI_{95} (−8.5, −2) $R^2 = .12$] and [$F_{1,75} = 15.85$, root $MSE = 31.88$, $p < .01$, $\beta = -.41$, CI_{95} (−1.42, −.47) $R^2 = .17$], correspondingly. We interpret this to show that both explicit and implicit judgments that one was agentic affect speed of action selection. However, when RT was simultaneously regressed on both predictors ($F_{2,\ 74} = 9.8$, $p = <.01$, $R^2 = .20$) only the number of the effects a participant received reliably predicted reaction time [$p < .01$, $\beta = -.32$, CI_{95} (−1.26, −.22)]; contingency awareness did not [$p = .07$, $\beta = -.20$, CI_{95} (−6.56, .31)].

We interpret the last piece of evidence to mean that the brain-mind's implicit judgment of agency affects (the speed of) action selection even when people's explicit judgment of agency is accounted for, but the opposite does not hold. Put differently, whatever the role of explicit judgment of agency in processes of action selection (here, key presses), the speed of action selection is determined by implicit judgment of agency.

Although the pattern of results fits our predictions well one can still argue that people perceived the effects as information about outcome. If this is indeed the case it nullifies our claim regarding the motivating effects of pure control. Experiment 2 attempts to directly tackle this alternative explanation.

3. Experiment 2 – decreasing temporal action-effect contingency diminishes motivation from control

In Experiment 1, we showed that having agency as 'having an effect' increases both the speed and frequency of response selection although the effect was unrelated to task performance. To rule out the alternative explanation we manipulated a factor that has repeatedly been shown to affect implicit markers of agency—the temporal contingency of action effect. Lagging the effects of an action by more than 300 ms (ms) has been shown to diminish sensory attenuation (Blakemore et al., 1999) and temporal binding (Haggard et al., 2002) both 'gold standard' behavioral markers of sensing agency. Because the temporal contingency between action and effect has been postulated as an important parameter for pre-conceptual implicit judgment of agency, we expect that it will mostly influence lower level processes (motor) of action selection and will less affect more high level (consciously accessible) processes of response selection.

Hence, if the mind's registration of an *own action* effect (vs. any perceived effect) influences low level process of action selection, we expect that the greater the number of temporally contingent (versus temporally lagged) action effects participants will receive, the shorter their reaction time will be. Conversely, there is no accepted model that leads to the prediction that lagging a positive outcome by about half a second should diminish its rewarding value.

To further explore whether positive judgments of agency influence action selection even when no relationship exists between agency (actual or perceived) and task performance, we tested whether the same response selection bias holds for participants who clearly did not interpret the effects as task relevant feedback (feedback about their progress towards the task goal to respond randomly).

3.1. Method

3.1.1. Participants

Ninety-three undergraduate students [67 females, Age (M = 24.1, SD = 3.94)] from the University of Haifa participated in the study in exchange for course credit or 20 Shekels (~$6).

3.1.2. Stimuli and procedure

In Experiment 2, we used the same task as in the Key Specific Effect condition in Experiment 1 with one modification. Participants were assigned to one of two conditions. In the Key Specific Immediate Effect condition (a replication), each response was associated with a different probability (90%, 60% 30% and 0%) of leading to an immediate effect. In the Key Specific Lagged Effect condition, keys were identically associated with different probabilities of effects with the sole difference that the effect was lagged by 600 ms.

Similar to Experiment 1, after completing the task, participants responded to a computerized self-report questionnaire in which participants were requested to indicate from 0 (not at all) to 100 (very much) their level of success in the task, how much they wanted the effect, how much they wanted to respond randomly and how much they felt they were causing the effect. In addition, participants had to report whether and how the effects they received were related to their performance of responding randomly. Participants were to select the option that best describes their belief: 1. 'When I responded randomly there was an effect'. 2. 'When I responded randomly there was no effect' or 3. 'Responding randomly and the effects were unrelated'.

3.2. Results

We applied the same filter used in Experiment 1 in which invalid responses, responses faster than 200 ms, and those that deviated more than two standard deviations from a condition's mean RT were dropped from the analysis (3241\ 17,280; 18.7% of the trials).

3.2.1. The effect of temporal contingency between action and effect

Similar to Experiment 1, we analyzed the correlation between the number of effects one had received and her reaction time in both the Key Specific Immediate and the Key Specific Lagged Effect conditions (Fig. 4). First, the results replicate the negative correlation between the two variables in the Key Specific Immediate Effect condition ($r = -.57$, $p < .01$). Second—and in line with our prediction—no evidence for such a relationship was found in the Key Specific Lagged Effect condition ($r = -.03$, $p = .81$); note that this is the case although there was no difference in the total number of effects participants received in those conditions ($t_{91} = -0.63$, $p = .53$). These results confirm that close temporal contingency is essential for an action contingent effect to facilitate response selection—as is the case with other measures which reflect implicit judgments of agency (such as sensory attenuation and temporal binding). As one could not make a similar prediction for similar lags in performance feedback, this experiment supplies critical evidence in support of our hypothesis that mere agency affects action selection.

To test whether response frequency as a proxy for high level selection is influenced by the temporal contingency of action effects, we again, as in Experiment 1 used the Dirichlet distribution to model proportions of presses on each key. Replicating the pattern found in Experiment 1, responses associated with a 90% chance to deliver an effect were selected more often in both the Key Specific Immediate Effect (M = .29, SD = .09) and the Key Specific Lagged Effect (M = .27, SD = .09) conditions compared to responses which never delivered an effect (M = .22. SD = .08) Z = 3.76, $p < .01$ and (M = .23. SD = .06) Z = 2.11, p = .03, correspondingly (Fig. 5). The findings suggest that in contrast to low level selection, high level selection (i.e., which finger to respond with) is not sensitive to short lags between the actions and their effects.

Participants explicit judgment of the level they caused the effects is also consistent with the above pattern of key selections in showing that there was no difference between conditions in how much they thought they were causing the effects ($t_{91} = 0.38$, $p = .70$). In contrast, participants reported a greater urge to have an effect in the Key Specific Immediate effect condition (M = 62.72, SD = 37.40) than in the Key Specific Lagged Effect condition (M = 47.98, SD = 31.60) ($t_{91} = -2.06$, $p < .05$) and their level of urge for the effect was also consistent with their behavioral pattern. Specifically, we found a negative correlation between participants' urge to have an effect and their reaction time in the immediate effect group ($r = -.34$, $p < .05$) and no correlation in the 600 ms lagged effect group ($r = .00$, $p = .98$).

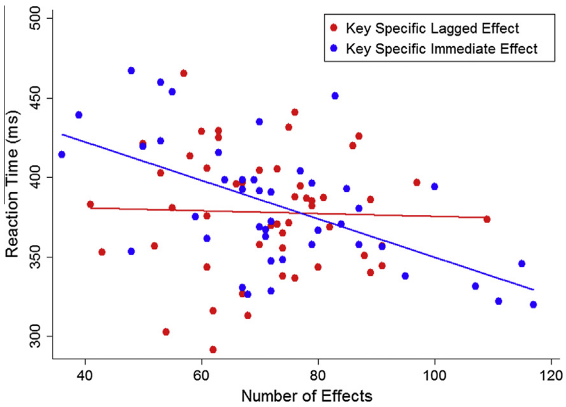

Fig. 4. Experiment 2: reaction time as a function of the number of effects received. A scatterplot with fitted regression lines representing participants' RT as a function of the number of effects a participant received in the Key Specific Immediate Effect and the Key Specific Lagged Effect conditions. The results show that responding sped up as the number of immediate effects (but not 600 ms lagged effects) received increased.

We suggest that high level selection of keys in this task is influenced by explicit attribution of causality which is unaffected by short temporal delay of action effect. As noted in Experiment 1, the opposite causal direction is also possible (see Supplemental materials for additional self-report analysis).

Finally, as in Experiment 1, we asked participants to rate their intention to cause an effect during the task as well as their perceived success in responding randomly (the task goal). Different from Experiment 1, Participants' ratings of the two measures were not correlated ($r = 0.01$, $p = .88$), still supporting the conclusion that they did not mistakenly perceive the effect as feedback about increased success in the task.

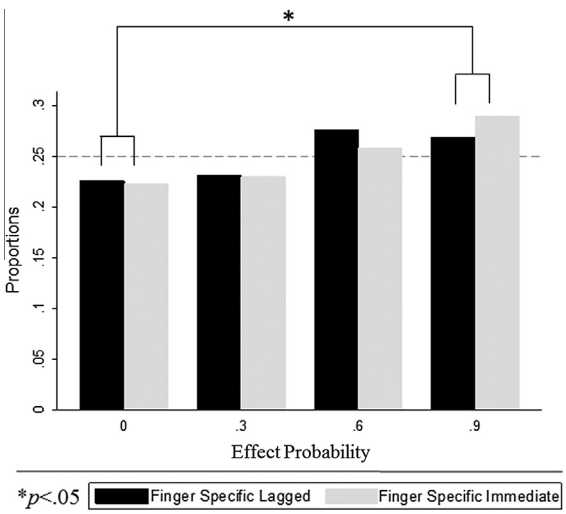

Fig. 5. Experiment 2: response frequency. Proportion of responses by each key-specific effect probability (.9, .6, .3, 0) in the Key Specific Immediate Effect and the Key Specific Lagged Effect conditions. The dashed horizontal line indicates chance level (.25). Participants' chose the key associated with the highest probability of delivering an effect reliably more often than they chose the key that never delivered one in both conditions.

3.2.2. Explicit beliefs about the nature of the effect do not affect the speed of action selection

In a further test of the alternative explanation that the action-effects influenced response selection because they were interpreted by participants as performance feedback (informative about the task goal to respond randomly), we asked participants at the end of the task to select one of three statements that best reflects their beliefs about whether and how the effects they received were related to their performance of responding randomly. Thirteen percent (13%) of the participants selected the option that indicates that when they responded randomly they received an effect, 17% selected the option that indicates that when they responded randomly they did not receive an effect and 70% of the participants selected the option that indicates that responding randomly and receiving effects were unrelated. While these percentages suggest that most participants did not perceive the effects as carrying any task relevant information, it is important to test which, if any, of the effects described above hold when the participants who did perceive effect as carrying task relevant information are removed from the analysis.

Regarding reaction time, the pattern reported above was unchanged by excluding participants that perceived the effect as performance feedback. Specifically, the number of immediate effects were negatively correlated with reaction time ($r = -.52$, $p < .01$) while no such correlation was detected between reaction time and the number of 600 ms lagged effects ($r = -.19$, $p = .27$).

Regarding response frequency, the immediate effect condition group ($n = 30$), filtered for the above mentioned participants, reliably selected the key with high probability to cause an effect more frequently ($M = .26$, $SD = .07$)) than the key producing no effect ($M = .23$, $SD = .05$) $Z = 2.12$, $p = .03$). Interestingly, no difference was found between the high probability key ($M = .25$, $SD = .07$) and the no-effect key ($M = .22$, $SD = .05$) $Z = 1.21$, $p = .22$ in the Key Specific Lagged Effect condition ($n = 35$).

The results from the analyses above strongly suggest that reaction time as a proxy for largely unconscious processes of response selection, was influenced by the effect, but only when effects closely followed a response and regardless of one's belief about the relation between the effect and task performance. In addition, while a portion of the variability of key selection could be explained by perceiving the effect as performance feedback, having own-action effects reinforces even once the information they carry about performance is factored out.

4. General discussion

The current study provides the first direct empirical evidence that mere control motivates behavior independently of (and even in some opposition to) striving for outcomes. These findings are consistent with various postulations that agency is itself rewarding, motivating, and desirable. The results also fit well with previous work from our lab (Eitam et al., 2013) using another task, in which we found that participants' correct responses are faster when they are immediately followed by an effect (compared to when no such effect appeared or when they were followed by a 300 ms lagged effect). Crucially, we go far beyond these results in providing the key dissociation between mere agency and desired outcome (e.g., successful task performance) and by grounding the abstract notion of motivation in contemporary neuro-cognitive of action selection.

The current study is a significant step in establishing the previously unexplored link between judgment of agency and its influence on action selection. The current pattern of results resembles the pattern found when responses were linked to tangible outcomes (e.g., food; Brown & Bowman, 1995; Samejima et al., 2005). In the latter case it was shown that tangible rewards activate the brain's reward system, which in turn biases action selection towards responses with the highest predicted reward value. Above we reviewed evidence that control has also been shown to activate the brain's reward system and in the current study we supply the crucial behavioral link by documenting that agency seems to indeed affect action selection (indexed by speed and frequency of responding) in manner that bears striking similarity to the effects of tangible outcomes.

To recapitulate based on the previous and current data we suggest a tentative model by which a positive judgment of agency activates the brain's reward system that in turn biases action selection towards actions that were associated with the largest amount of agency.

Given the frequent use of the term 'reward' in reference to obtaining beneficial outcomes, the notion of control as reward may sound strange. In fact, dissociating between reward and tangible outcomes is consistent with recent work in neuroscience suggesting that the neural reward system is sensitive to various non-outcome related factors (Bednark & Franz, 2014; Behne et al., 2008; Bromberg-Martin & Hikosaka, 2009; Leotti & Delgado, 2011; Tricomi et al., 2004).

Finally, our results also begin to shed light on the differential contribution of what we elsewhere-termed implicit and explicit 'decisions of agency' (Karsh & Eitam, in press). The current data seems to support the conclusion that selection of action (possibly at the 'lower', motor related level) is affected by *implicit* judgment of agency. Here reflected in the speed of action selection. Another, albeit weaker, conclusion is that explicit judgments of agency may too have a causal role in selecting which (and possibly also how fast) actions will be selected. Thus, although Libet's classic studies taught us that the relationship between other experiences of agency and action selection may not be in fact causal, the data of the current study (which also focuses on a different 'experience' of agency) is actually inconclusive regarding this last point.

Understanding control as reward affecting action selection (potentially, at multiple levels of abstraction) offers the beginning of a mechanistic framework for the documented effects that the so-called 'sense of control' has on promoting physical activity, self-initiation and social interest (Rodin & Langer, 1977). It may also explain when and why people would be willing to give up real money (own outcomes) for affecting the outcome of others (Choshen-Hillel & Yaniv, 2011), and possibly the fact that people want to choose regardless of the outcomes choice brings (Botti & McGill, 2006) as choice itself is (an opportunity to) control (Leotti & Delgado, 2011).

Our tentative model may also encourage reframing a variety of pathological behaviors not easily explained through referring to pursuing positive outcomes such as impulsivity (attention-deficit/hyperactive disorder), stereotypy (repetitive motor actions) and self-mutilation, as disorders of control (see, Brandt, Lynn, Obst, Brass, & Munchau, 2014; Karsh & Eitam, in press).

Author contributions

N. Karsh and B. Eitam developed the study concept. Both authors contributed to the study design. N. Karsh collected the data. N. Karsh and B. Eitam performed the data analysis and interpretation. N. Karsh and B. Eitam wrote the paper. Both authors approved the final version of the manuscript for submission.

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Appendix A. Supplementary material

Supplementary data associated with this article can be found, in the online version, at http://dx.doi.org/10.1016/j.cognition.2015.02.002.

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