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The relation between the sense of agency and the experience of flow

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ABSTRACT

This article investigates the relation between people's feelings of agency and their feelings of flow. In the dominant model describing how people are able to assess their own agency—the comparator model of agency—when the person's intentions match perfectly to what happens, the discrepancy between intention and outcome is zero, and the person is thought to interpret this lack of discrepancy as being in control. The lack of perceived push back from the external world seems remarkably similar to the state that has been described as a state of flow. However, when we used a computer game paradigm to investigate the relation between people's feelings of agency and their feelings of flow, we found a dissociation between these two states. Although these two states may, in some ways, seem to be similar, our data indicate that they are governed by different principles and phenomenology.

1. Introduction

Gallagher (2007, p. 348) defined the sense of agency as "the pre-reflective experience or sense that I am the cause or author of the movement (e.g., an experience that I am in control of my action)". For example, if I reach to pick up a glass, I may actually have a sense of control over the movement and so have a sense of agency for this movement; if I am then asked, did I reach for the glass, I can correctly attribute agency to myself: 'Yes, I was the one who reached for the glass.'

Cognitive models have made considerable progress in pointing to the informational basis for such feelings of control. The most widely accepted computational model addressing this question is the comparator model (Blakemore, Frith, & Wolpert, 1999; Wolpert, Ghahramani, & Jordan, 1995). This model was initially proposed to solve the problem of how people are able to achieve fast, finely-tuned and flexible online control of movements. Wolpert and colleagues (Wolpert & Flanagan, 2001; Wolpert et al., 1995) proposed that the actual sensory feedback of movement is compared to its predicted feedback. When a discrepancy between the predicted and actual feedback occurs, it can be used to immediately correct the movement. But the comparison can also be co-opted for other purposes: Blakemore, Frith and others (Blakemore & Frith, 2003; Blakemore, Wolpert, & Frith, 1998; Blakemore et al., 1999) proposed that this comparison information could serve as the basis for people's sense of agency. When a large discrepancy at the locus of convergence for the actual and predicted feedback (the comparator) is detected, it means that there was a large difference between the person's intentions and what happened and therefore that the person was not in control. In contrast, when there is little to no difference between the two signals, it

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means that the person's intentions are being smoothly actualized, and the person is in control. The smoothness that sometimes accompanies and is a cue for the positive sense of agency—where the person's intentions play out without apparent opposition from the outside—is highly reminiscent of the reports that people give when they are experiencing a state of effortless flow.

A common model describes feelings of flow as a function of skills and task demands. When the task demands match the actor's skills, people are prone to experience flow. When demands exceed skills, people become anxious. They become bored when they are too skilled for the current demands (the *balance* hypothesis, Csikszentmihalyi, 2009; Rheinberg & Vollmeyer, 2003). Recently, this model was augmented to include people's judgments of performance. Flow judgments are highest when skills and demands are in balance *and* when they think they are performing well (the *balance plus* hypothesis; Kennedy, Miele, & Metcalfe, 2014).

The experience of flow is reported across a range of activities, including sports, music, mountaineering, painting, and gaming, and is described as a pleasurable and motivating immersion in the current activity (Csikszentmihalyi, 2009; Massimini & Carli, 1988). The flow state is similar to the heightened state of consciousness that is sometimes, especially in sports, described as a feeling of being in the zone, or having a "hot hand" in basketball (Gilovich, Vallone, & Tversky, 1985; Young & Pain, 1999). In the literature, the terms zone and flow are often used interchangeably (Young & Pain, 1999), and we do so here as well. Crucially, when the person is 'in the zone' or in a state of flow, there is a feeling of effortlessness, and lack of resistance from the world. For instance, Roger Bannister, in describing his four-minute mile breaking run says: "Brasher went into the lead and I slipped in effortlessly behind him. My legs seemed to meet no resistance, as if propelled by some unknown force" (Bannister, 2014). Similarly, Hales (1999, p. 79) reported that when five time Wimbledon champion, Björn Borg, was at the height of his powers, he described the feeling that he "could do anything—put the ball on a dime at any angle, anywhere on the court, at any speed he chose, with the spin he wanted." Note that Borg's description emphasizes precise control over his actions and their outcomes; this sense of control is considered an important characteristic of the flow state (Nakamura & Csikszentmihalyi, 2002).

There have been no studies in which the relation between agency and flow has been explicitly tested. However, Wenke, Fleming, and Haggard (2010, and see Chambon & Haggard, 2012; Chambon, Sidarus, & Haggard, 2014; Sidarus, Chambon, & Haggard, 2013; Stenner et al., 2014) investigated the effect of subliminal priming of actions on people's feelings of agency. They found that the increases in action selection fluency due to such priming resulted in increases in people's sense of control over the effects of their action. Wenke et al. (2010, p. 36) noted: 'Our key finding is that this smoothness produces a heightened sense of control. This is in keeping with the notion that during a well-learned, skilled task such as playing the piano, people often report mastery of what they are doing, and a feeling of "flow" (Csikszentmihalyi, 2000).'

Although the previous considerations suggest similarities between flow and agency, there also may be important differences between these two states. For instance, the relationship between experienced control and the flow state is sometimes called paradoxical (Young & Pain, 1999). Flow requires control over actions, but is thought to also involve a loss of awareness of oneself as a (social) actor (Nakamura & Csikszentmihalyi, 2002, p. 90), suggesting that these two experiences might not be the same.

The hypothesis that motivated the present study was that there would be convergence between people's sense of agency and feelings of flow. We began with the findings of Kennedy et al. (2014) who demonstrated that the feeling of flow can be manipulated by having participants play a computer game in which X's and O's scroll from the top of the screen, and the participants' task is to move a mouse controlling a cursor in such a way as to catch the X's while avoiding the O's. They varied the speed of the scroll, and found a non-monotonic relation between people's feelings of flow and speed. People tended to experience the highest levels of flow at moderate speeds—speeds at which they were maximizing the number of X's that they hit over the 20 s game interval. Less flow was experienced when the speed was either too high or too low. People also experienced an increase in flow when they had the metacognitive feeling that their performance was particularly good on that trial (regardless of whether their performance actually had been particularly good). Kennedy et al. (2014), did not look at agency judgments. However, the computer game that they used has been used in other studies that have investigated people's feelings of agency (see, Metcalfe, Eich, & Castel, 2010; Metcalfe, Eich, & Miele, 2013; Metcalfe & Greene, 2007; Metcalfe, Snellenberg, DeRosse, Balsam, & Malhotra, 2012; Miele, Wager, Mitchell, & Metcalfe, 2011). In the first experiment that we present here, we simply took exactly the same game that Kennedy et al. (2014) had used, but instead of asking people for judgments of flow (what Kennedy et al. called 'Z' scores), on each trial, we asked them for judgments of agency (how in control they felt). Our expectation was that we would obtain agency functions that were virtually identical to those reported for flow by Kennedy et al. (2014).

2. Experiment 1

2.1. Method

2.1.1. Participants

The sample of 14 participants (3 males and 11 females, M_{age} = 20 years) were students in an Introductory Psychology course at Columbia University and received partial course credit for their participation. All participants were treated in accordance with APA regulations, and the ethical guidelines of the Psychonomic Society.

2.1.2. Design

Each 20-s trial of the computer game task involved using a mouse to move a cursor along a horizontal track at the bottom of the screen as stimuli (Xs and Os) that were randomly distributed from left to right scrolled down from the top of the screen to the bottom (the total number of stimuli depended on the speed of the game). The Xs or Os disappeared as soon as they were "touched" by the cursor, but continued to scroll past the horizontal track if they were not touched. In addition, a distinctive BONK sound occurred each time an X was hit and a THUD sound occurred each time an O was hit. Seven different experimental conditions were created by manipulating the speed with which the Xs and Os scrolled down the screen. The entire session included 21 trials grouped into 3 blocks, such that each block contained trials from all 7 speed conditions. The order of conditions within each block was pseudorandom.

2.1.3. Procedure

After completing a demographic questionnaire (which included questions about their experience playing video games), participants were told that they would be playing a game in which the purpose was to use the mouse to touch the Xs when they came into range of the cursor box and to avoid touching the Os. Participants then read a brief passage about feelings of agency: "In this experiment, we are interested in people's metacognitions of control or their feelings about when they are causing things to happen. You have probably heard stories, and maybe even have had the experience of going to an arcade and you start playing a video game—thinking you are controlling what is happening. But when you let go of the levers it just keeps on happening: you weren't actually controlling anything, but you thought you were. Metacognition of control can differ in more mundane circumstances too. Sometimes if you are driving, the steering may be such that you don't feel like you are in control. At other times you simply know that you are controlling every move. Regardless, then, of whether you actually are in control or not (which is not our question here) you may sometimes feel like you are in control (and hence have a high metacognition of control) or feel like you are not (and have a low metacognition of control)." Note that this judgment was substituted into the program used by Kennedy et al. (2014), to replace the judgments of flow or of 'being in the zone' that had been requested following each game, in their experiment. Otherwise, this experiment was identical to their Experiment 1.

Following a practice trial, participants completed the 3 blocks of experimental trials. After each trial, they were asked to make both agency judgments, indicating how in control they felt, and judgments of performance (JOPs). For agency judgments, participants were presented with a visual analogue scale labeled "Amount of CONTROL" and were asked to pull the slider toward the left end if the amount of control they experienced was "None" or to the right end if the amount they experienced was "Complete." For performance, they were presented with a scale labeled "Performance" and were instructed to pull the slider to the left end if they felt that they had gotten "None correct" or to the right end if they felt they were "Completely correct." In between each block of trials, participants completed a 20-s distractor task that involved subtracting by 3's from a randomly presented three-digit number.

2.2. Results

2.2.1. Statistics

We specified a multilevel linear regression model (e.g. Gelman & Hill, 2007) to estimate the main effects of speed (linear and quadratic) and JOPs (standardized within participants) on participant's agency judgments. All effects were estimated at the average level (fixed effects) and as varying at the participant level (random effects) to appropriately account for the clustering of data and possible between-participants heterogeneity in effects. We used orthogonal polynomials to estimate the linear and quadratic effects of speed on the agency judgments (the linear predictor of speed was scaled to range from −0.57 to 57).

We adopted a Bayesian approach to estimating the model parameters, because it is especially suitable for multilevel models (Gelman & Hill, 2007), and approximated the posterior distribution by Hamiltonian Monte Carlo sampling as implemented in the Stan programming language (Stan Development Team, 2015.) We ran four HMC chains of 30,000 iterations, discarding the first 5000 values of each chain, leading to a total of 100,000 samples from the posterior distribution. The samples from the posterior distribution were analyzed with the R programming language (R Core Team, 2015). We used a uniform prior for the intercept parameter, Normal(M = 0, SD = 50) distributions as priors for the average level regression parameters, and half-Cauchy(location = 0, scale = 50) priors for the hierarchical variance components (random effects' standard deviations) Because of the scale of the data (judgment range: 0–100), these priors were minimally informative, but we also estimated the model with a variety of priors (including uniform) to confirm the results. We also estimated the model using standard maximum likelihood methods (Bates, Mächler, Bolker, & Walker, 2015), and found the same results. For parameters estimated with the Bayesian model, we report posterior means ($\hat{\beta}$) and their associated 95% Credible Intervals (CI; the central 95% of values in the respective posterior distribution.)

2.2.2. Results

As is shown in Fig. 1, people's judgments of agency were a monotonically decreasing function of speed (linear effect of speed $\hat{\beta} = -17.14$, 95% CI [−29.54, −4.51]; quadratic effect of speed $\hat{\beta} = -2.34$, 95% CI [−7.18, 2.46]). Additionally, higher judgments of agency were associated with higher judgments of performance ($\hat{\beta} = 10.46$, 95% CI [4.68, 16.39]).

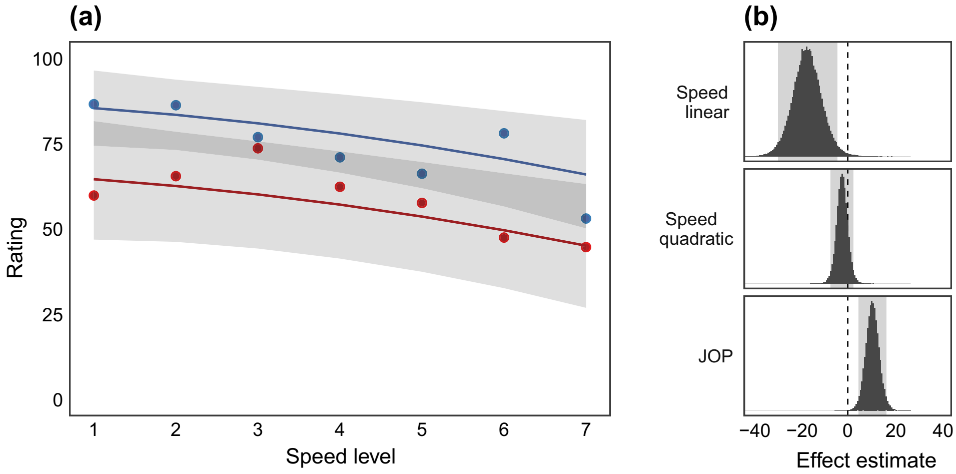

Fig. 1. Bayesian multilevel linear regression model of Agency judgments from Experiment 1. (a) Agency ratings as a function of game speed and Judgments of Performance (blue = high JOP; red = low JOP). Circles are means from raw data, regression lines at ±1 SD of JOP are displayed with 95% CIs as gray shades. (b) Histograms of 100,000 samples from the posterior distribution of the regression parameters with 95% CIs (gray shades). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

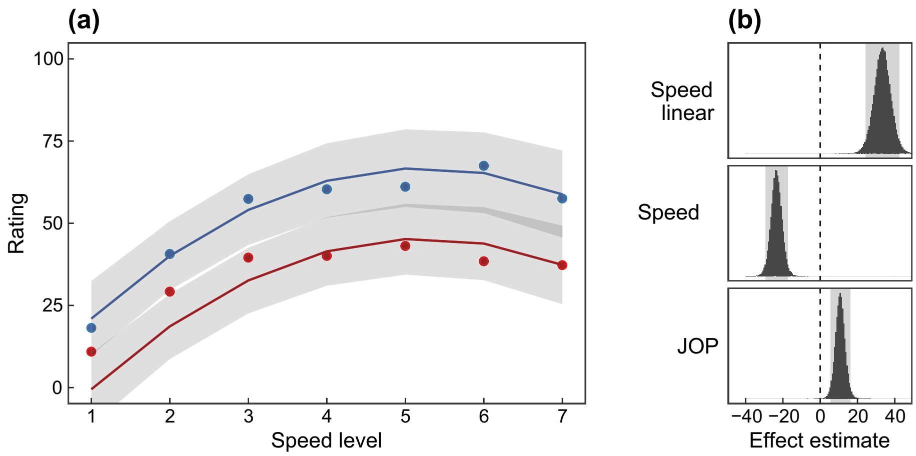

Fig. 2. Bayesian multilevel linear regression model of Zone judgments from Kennedy et al. (2014). (a) Zone judgments as a function of game speed and Judgments of Performance (blue = high JOP; red = low JOP). Circles are means from raw data, regression lines at ±1 SD of JOP are displayed with 95% CIs as gray shades. (b) Histograms of 100,000 samples from the posterior distribution of the regression parameters with 95% CIs (gray shades). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

For comparison, we reanalyzed the data from Kennedy et al.'s (2014) Experiment 1 in the same manner. As is shown in Fig. 2, the zone judgments in Kennedy et al. (2014) followed the inverted u-shaped function as was reported in the original paper (linear effect of speed $\hat{\beta} = 33.36$, 95% CI [24.3, 42.39]; quadratic effect of speed $\hat{\beta} = -23.44$, 95% CI [-29.35, -17.51]; JOP $\hat{\beta} = 10.74$, 95% CI [5.59, 16.07]). While both types of judgments (agency and flow) were positively associated with judgments of performance, the basic shape of the agency function (Fig. 1a) was quite different from that of the flow function (Fig. 2a): The former was a decreasing linear function with no quadratic component, and the latter was quadratic with a linear increase.

2.3. Discussion

The first experiment suggested that our initial conjecture—that the experiences of flow and agency were isomorphic—was wrong. However, different participants were run in our experiment and in that of Kennedy et al. (2014). Furthermore, the number of participants in Experiment 1 was small, and we wanted to be sure that those results replicated. To compare the phenomenology of flow and agency within individuals, then, we conducted Experiment 2 in which the same participants gave both types of judgments in a within-participant design.

3. Experiment 2

3.1. Method

3.1.1. Participants

We recruited 25 participants (18 females and 7 males, $M_{age} = 24$ years) from an Introductory Psychology course at Columbia University who received partial course credit for their participation. All participants were treated in accordance with APA regulations, and the ethical guidelines of the Psychonomic Society.

3.1.2. Procedure and design

All participants did both the agency condition, with 21 trials, including 3 blocks with each of the 7 speeds, each followed by judgments of agency and then judgments of performance, and the flow condition, in which, following each trial they gave their 'Z' scores, followed by judgments of performance. We used the same instructions to illustrate what flow (the feeling of being in the zone) was, that had been used by Kennedy et al. (2014). In particular, before beginning the flow trials, participants read a brief passage about zone, or "Z-factor", that included descriptions of flow (Csikszentmihalyi, 2000) and the hot hand (Gilovich et al., 1985), as well as a quote from the soccer player Pelé (Pelé & Fish, 2013), and other instructions used by Kennedy et al. (2014):

> "In this part of the experiment, we are interested in your experiences of being fully immersed in a feeling of energized focus, of full involvement, and of enjoyment which is characterized by a complete absorption in what you were just doing. In sports this may be known as 'being on fire' or in music as 'being in the groove.' It is a specific feeling in which everything seems to flow in such a way that it feels like everything is going your way. The legendary soccer player Pelé described his experience as feeling '...a strange calmness...a kind of euphoria. I felt I could run all day without tiring, that I could dribble through any of their team or all of them, that I could almost pass through them physically.' For the present purposes we will call this feeling, or this state of being 'in the zone,' the Z-factor. We will ask you to rate how much of this feeling you had—from a very low z-score to a very high z-score."

After each trial in this block, participants reported their Z-score on a ~10 cm visual analogue scale ranging from "Very Low" to "Very High." Half of the participants did the 21 agency trials first followed by the 21 Z-score trials; the other half did the Z-score trials first, followed by the agency trials.

3.2. Results

We analyzed the data in four ways: (1) a Bayesian analysis as described for Experiment 1, (2) a factorial ANOVA in which type of judgment was treated as if it were an independent variable, and (3) using two separate multilevel regression models similar to the Bayesian analysis, but additionally using the participants' average agency judgments to predict flow judgments, and vice versa. Finally, (4) we examined the relationships between the two types of judgments and two performance metrics.

3.2.1. Bayesian regression model

We specified a multilevel linear regression model identical to the one described for Experiment 1, but with an additional dummy predictor for judgment type (0 = agency judgment, 1 = flow judgment), and interaction terms between the judgment type dummy predictor, and the other predictors. These results replicated the findings of Experiment 1 and those of Kennedy et al. (2014). Participants' agency judgments were a monotonically decreasing function of game speed, but there was an additional small quadratic component (linear effect of speed $\hat{\beta} = -15.11$, 95% CI [−23.31, −6.80]; quadratic effect of speed $\hat{\beta} = -3.73$, 95% CI [−6.68, −0.78]). Participants' flow judgments displayed a strong linear increase and quadratic component (linear effect of speed $\hat{\beta} = 15.75$, 95% CI [4.97, 26.34]; quadratic effect of speed $\hat{\beta} = -13.75$, 95% CI [−21.54, −5.99]). Importantly, the interaction terms indicated that the differences in the linear and quadratic effects of game speed between agency and flow judgments were large and plausibly non-zero (linear effect by judgment type interaction $\hat{\beta} = 30.87$, 95% CI [17.84, 43.66]; quadratic effect by judgment type interaction $\hat{\beta} = -10.02$, 95% CI [−17.99, −2.04]). Additionally, JOPs were positively associated with higher agency ($\hat{\beta} = 8.65$, 95% CI [5.64, 11.83]) and flow ($\hat{\beta} = 9.89$, 95% CI [6.62, 13.26]) judgments; judgment type and JOP did not interact ($\hat{\beta} = 1.24$, 95% CI [−1.41, 3.93]). These results are displayed in Fig. 3.

3.2.2. ANOVA

We also conducted a 2 (Judgment type: Agency, Zone) × 7 (Speed level) ANOVA (Greenhouse-Geisser corrected for violations of sphericity) confirming that speed exerted a significant effect on judgments ($F(2.1, 50.9) = 11.7$, $p < 0.001$, $\eta_p^2 = 0.33$), and that the effect of judgment type was significant ($F(1, 24) = 15.43$, $p < 0.001$, $\eta_p^2 = 0.39$). Importantly, the speed by judgment type interaction was also significant ($F(2.2, 52.4) = 15.5$, $p < 0.001$, $\eta_p^2 = 0.39$). Bayes factors for all three effects indicated decisive evidence for the effects over their respective null models (models including all lower-level terms; all BF_{10}s > 100; Love et al., 2015; Rouder, Morey, Speckman, & Province, 2012). These results are displayed in Fig. 4; while agency ratings

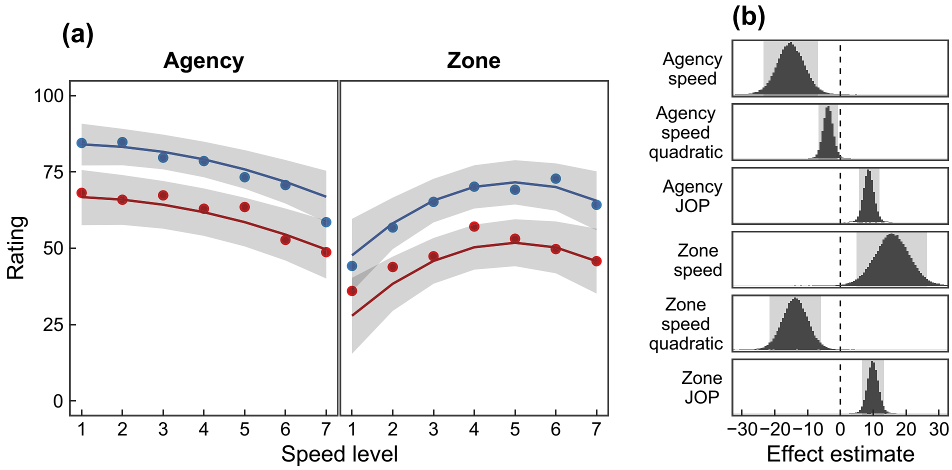

Fig. 3. Bayesian multilevel linear regression model of Agency and Zone judgments from Experiment 2. (a) Judgments as a function of game speed and JOP (blue = high JOP; red = low JOP). Circles are means from raw data, regression lines at ±1 SD of JOP are displayed with 95% CIs as gray shades. (b) Histograms of 100,000 samples from the posterior distribution of the regression effects with 95% CIs (gray shades). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

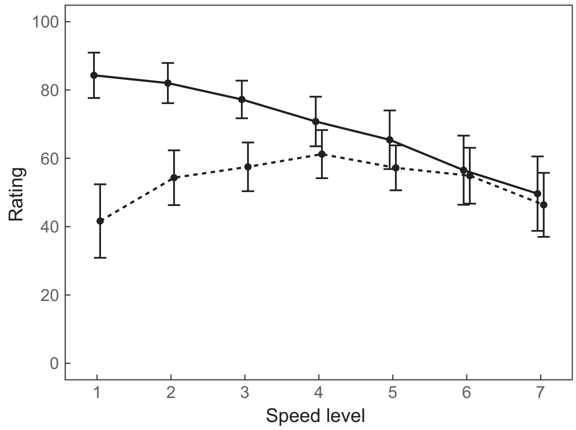

Fig. 4. Average Agency (solid line) and Zone (dashed line) judgments at each of the 7 levels of speed, in Experiment 2. Errors bars are 95% CIs.

were significantly higher than zone judgments for low speeds, these two types of judgments converged, on average, for faster game speeds.

3.2.3. Separate regressions

We then asked whether participants' mean agency judgments predicted their zone judgments, and vice versa, by analyzing each judgment type with a separate multilevel linear regression model. These models included as predictors the linear and quadratic game speed, JOPs as standardized between- and within-person predictors (Bolger & Laurenceau, 2013), and the subject-specific mean of the other judgment as a standardized between-person predictor. Linear and quadratic speed, and the within-person JOPs were modeled as fixed and varying effects between participants. These regression models were fitted with standard maximum likelihood methods using the *lme4* package in the R statistical programming environment (Bates et al., 2015; R Core Team, 2015); *p*-values for the regression parameters were computed using the Satterthwaite approximation (Kuznetsova, Brockhoff, & Christensen, 2015).

These results, again, confirmed that the sense of agency was a monotonically decreasing function of game speed—albeit with a slight quadratic trend that was confirmed to be much smaller than the quadratic effect for zone judgments in the Bayesian analysis—and that JOPs were positively associated with agency judgments (linear effect of speed $\hat{\beta} = -14.54$, 95% CI [−22.96, −6.08], $p = 0.002$; quadratic effect of speed $\hat{\beta} = -3.83$, 95% CI [−6.79, −0.89], $p = 0.016$; JOP within-subjects $\hat{\beta} = 10.31$, 95% CI [7.38, 13.32], $p < 0.001$). Additionally, we found that JOPs predicted agency ratings between individuals: Participants who perceived their performance to be better, on average, gave higher judgments of agency than people who judged their performance to be poorer (JOP between-subjects $\hat{\beta} = 18.65$, 95% CI [5.66, 31.51], $p = 0.005$). Participants' average zone judgments did not predict how in control they felt ($\hat{\beta} = -6.06$, 95% CI [−18.92, 6.79], $p = 0.26$).

As for the zone judgments, we confirmed the earlier results (linear effect of speed $\hat{\beta} = 16.57$, 95% CI [7.80, 25.39], $p < 0.001$; quadratic effect of speed $\hat{\beta} = -13.94$, 95% CI [−21.22, −6.66], $p < 0.001$; JOP within-subjects $\hat{\beta} = 12.16$, 95% CI [9.44, 15.05], $p < 0.001$), and additionally found that JOPs are positively associated with zone judgments between individuals (JOP between-subjects $\hat{\beta} = 22.50$, 95% CI [16.82, 28.23], $p < 0.001$). This model also revealed that participants' average agency judgments were negatively associated with their zone judgments: Participants who, on average, felt more in control, reported lower levels of feelings of being in the zone ($\hat{\beta} = -7.54$, 95% CI [−12.78, −2.06], $p = 0.004$). These results are shown in Fig. 5.

3.2.4. Relationship with judgments and performance

Finally, we asked how agency and zone judgments relate to hit rate (proportion of Xs touched, of all possible Xs, in a trial) and 'reward' (an approximation of the absolute amount of reward the person obtained on each trial, calculated as the num-

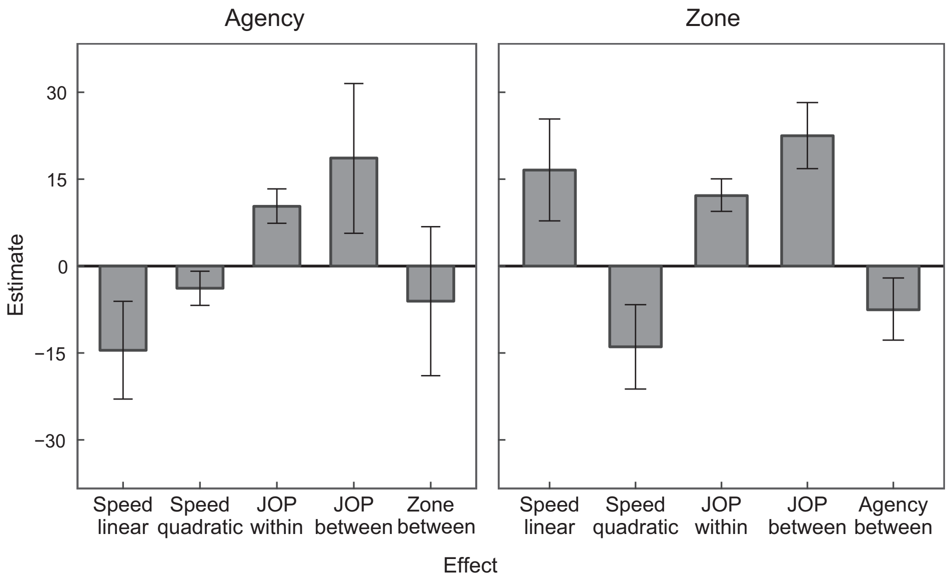

Fig. 5. Average regression coefficients (with 95% Confidence Intervals) from regression analyses where agency judgments (left) and zone judgments (right) were regressed on linear and quadratic speed, within- and between-subjects standardized judgments of performance (JOP) and the subject-specific mean of the other judgment (between-subjects effect).

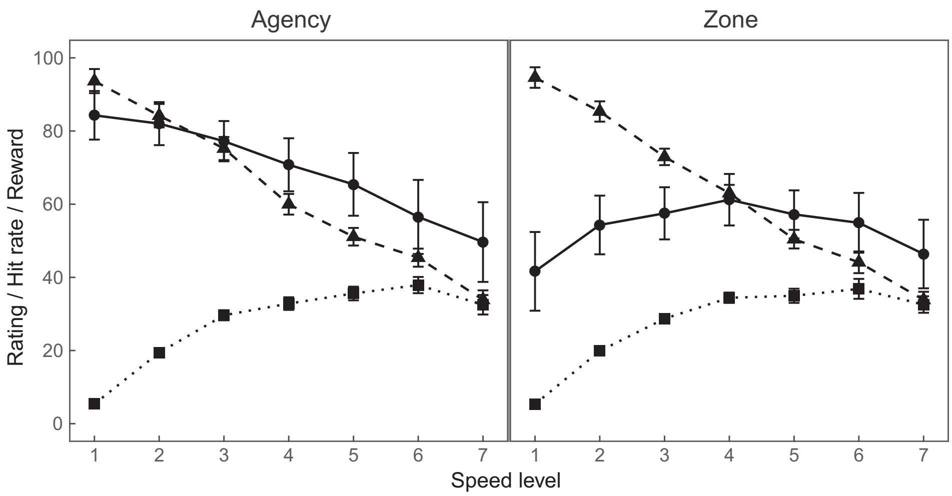

Fig. 6. Average Agency and Zone judgments (solid lines), hit rates (dashed lines), and reward (dotted lines) at each 7 speed levels, Experiment 2. Error bars are 95% CIs.

ber of hits). Based on the results of Kennedy et al. (2014) we expected the zone judgments to be most similar to reward, and that the pattern of agency judgments would be most similar to proportion correct. As observed in Fig. 6, Zone judgments mirrored participants' reward: both displayed a quadratic association with speed. In contrast, agency judgments were more similar to proportion correct, which both displayed a linear association with speed. We then examined the within-participant relationship between reward and the two types of judgments with separate multilevel linear regressions for each (standardized) judgment predicting reward: Reward was negatively associated with Agency judgments ($\hat{\beta} = -4.33$, SE = 0.82, $p < 0.001$), but positively associated with Zone judgments ($\hat{\beta} = 3.85$, SE = 1.23, $p = 0.004$). In contrast, hit rate was positively associated with Agency judgments ($\hat{\beta} = 12.03$, SE = 1.30, $p < 0.001$), but not significantly associated with Zone judgments ($\hat{\beta} = -0.21$, SE = 2.12, $p = 0.92$). Judgments of performance, and actual performance (hit rate) were highly positively correlated (mean within-participant correlation $r = 0.56$, 95% CI [0.48, 0.65]).

These results suggested another qualitative dimension in which Zone and Agency experiences differ: Agency closely tracks the person's objective task performance whereas Zone is more sensitive to the absolute rewards obtained in the game.

4. General discussion

We found a robust dissociation between the sense of agency—the experience that 'I am in control of my actions' and their outcomes—and the feeling of flow—the effortless, pleasurable absorption in a task. Specifically, the sense of agency decreased as the task became more difficult, whereas the feeling of flow peaked at middle values of difficulty, where task demands and the person's abilities are in balance (Kennedy et al., 2014; Rheinberg & Vollmeyer, 2003). Furthermore, we found that participants who, on average, felt a stronger sense of agency, felt lower levels of flow than individuals who reported lower average levels of agency, but more research is needed to specifically address this relationship. However, we also found one dimension in which these metacognitive evaluations were similarly influenced: Both experiences were positively influenced by judgments of performance: Higher judgments of performance were associated with an elevated sense of agency and feeling of flow.

Although previous experimental work has not directly addressed the relationship between the sense of agency and the experience of flow, it has been suggested that they are, to some degree, similarly influenced by the "smoothness" or experienced ease of the current task or action (Wenke et al., 2010). Contrary to this hypothesis, we showed that while the sense of agency is at its highest when the task is easy it decreases linearly as the task becomes more difficult. The experience of flow shows an entirely different pattern: Evaluations of flow increase as the task becomes more difficult, and peak at middle values of difficulty, where skills and demands are in balance.

The present results are consistent with previous findings showing that the sense of agency is reduced by difficulty or dysfluency (Sidarus & Haggard, 2016, but note, this study provided no evidence on whether or not the sense of agency was increased by increased fluency). Other previous studies, however, have suggested a relationship between increased experiences of agency and increased flow, suggesting that both require a 'smoothness', or ease of action (Wenke et al., 2010). The present results indicate that the relationship between the experience of control and 'flow' is more complicated than initially suggested, and these complex results may reflect an important, but unexplored, distinction between action fluency and the feeling of flow.

In another study investigating individuals' proneness to experience flow in the popular game Tetris, Keller and Blomann (2008) found that individuals who had a greater internal Locus of Control (LOC, e.g. Rotter, 1990) were more prone to experience flow states. Internal LOC is thought to index the degree to which individuals believe that their actions and efforts are instrumental in obtaining desired outcomes (in contrast to *external* LOC, reflecting beliefs that outcomes are not contingent on one's efforts). Insofar as internal LOC reflects *beliefs* associated with a high degree of *sense* of agency, our results are in contradiction with Keller and Blomann's (2008) results. We showed that when the experience of agency in a task is directly assessed, people who, on average, felt a stronger sense of agency reported lower levels of flow, and that the sense of agency and feelings of flow are differently influenced by task demands. This consideration suggests that the general belief in the causal impact of one's actions (internal LOC), and the experience of controlling one's actions (sense of agency) might not be directly related. Furthermore, the sense of being able to control one's actions is often thought to be an important, though it is sometimes described as a paradoxical (see Young & Pain, 1999), characteristic of the flow experience (Keller & Blomann, 2008; Nakamura & Csikszentmihalyi, 2002). Our results further complicate this component of the phenomenology of flow.

The fact that agency ratings decrease monotonically with game difficulty, but flow ratings do not, suggests that the sense of agency is at least partly a metacognitively accurate judgment of people's ability to control their actions and those actions' outcomes in the game (Metcalfe & Greene, 2007). Indeed, agency ratings were strongly related to both judgments of performance and to actual proportion correct. In contrast, the quadratic relationship between flow ratings and game difficulty suggest that the flow state has less to do with metacognitive evaluations of one's control in the task, but instead reflects the match of skills and task demands, a positive assessment of one's performance, and perhaps how enjoyable the experience is (Csikszentmihalyi, 2009; Kennedy et al., 2014). And, indeed, flow ratings were strongly associated with reward – the absolute number of X's the person exploded during the entire trial – but not performance when the latter is computed as a proportion correct. Notably, on slow games performance and reward are quite different. A person may hit all of the X's in slow game (and hence have a high proportion correct, and a high sense of agency) but if there were only 3 or 4 such X's, because the game was so slow, the reward (and hence the sense of flow) may be small. At the fast speeds, proportion correct decreases because the game is very difficult, but it turns out that reward, or the number of X's hit over the entire trial, decreases as well because the X's pass by so quickly that the person cannot explode them (Fig. 6).

Another important distinction between the experiences of flow and agency is the degree to which the experienced self is involved in either state. An important characteristic of the flow state is a ''Loss of reflective self-consciousness (i.e., loss of awareness of oneself as a social actor)" (Nakamura & Csikszentmihalyi, 2002, p. 90). In contrast, the central involvement of the self as the actor is a defining feature of the sense of agency (knowing that ''I am the actor"; Gallagher, 2007). These different descriptions would be difficult to reconcile, if the sense of agency and the experience of flow were indeed one and the same—which they are not, as shown by the current results.

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