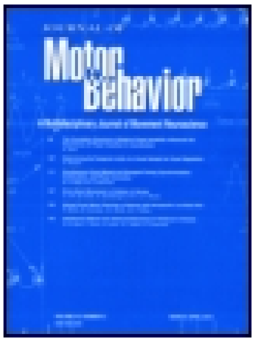

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RESEARCH ARTICLE

Anxiety Influences the Perceptual-Motor Calibration of Visually Guided Braking to Avoid Collisions

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ABSTRACT. We investigated whether anxiety influences perceptual-motor calibration in a braking to avoid a collision task. Participants performed either a discrete braking task (Experiment 1) or a continuous braking task (Experiment 2), with the goal of stopping before colliding with a stop sign. Half of participants performed the braking task after an anxiety induction. We investigated whether anxiety reduced the frequency of crashing and if it influenced the calibration of perception (visual information) and action (brake pressure) dynamically between-trials in Experiment 1 and within-trials in Experiment 2. In the discrete braking task, anxious participants crashed less often and made larger corrective adjustments trial-to-trial after crashing, suggesting that the influence of anxiety on behavior did not occur uniformly, but rather dynamically with anxiety amplifying the reaction to previous crashes. However, when performing continuous braking, anxious participants crashed *more* often, and their within-trial adjustments of deceleration were less related to visual information compared to controls. Taken together, these findings suggest that the timescale and nature of the task mediates the influence of anxiety on the performance of goal-directed actions.

Keywords: anxiety, visually guided actions, braking, dynamical systems, ecological psychology

Understanding how organisms adaptively detect perceptual information to control their actions is a fundamental area of inquiry for perceptual and motor control scientists. Anxiety has been shown to be an important factor in the performance of perception-action tasks, such as golfing or rock climbing (Beilock, 2010; Deschamps, Nourrit, Caillou, & Delignieres, 2004; Higuchi, 2000; Higuchi, Imanaka, & Hatayama, 2002; Nieuwenhuys, Pijpers, Raoul, Oudejans, & Bakker, 2008; Nourrit, Delignieres, Caillou, Deschamps, & Lauriot, 2003). However, the literature on how and when anxiety influences perception-action remains mixed, especially when considering how anxiety could affect perceptual-motor calibration (the scaling between visual information and actions) across different timescales. By using a task in which the relationship between perception and action is well understood (the visual guidance of braking to avoid collisions) and by investigating braking performance within-trials, between-trials, and across braking tasks with different constraints (i.e., emergency braking as compared to braking regulated over time), we hope to clarify how and when anxiety influences perceptual-motor calibration.

The Influence of Anxiety on Perception-Action

Anxiety is an uncomfortable feeling that arises from a subjective evaluation of a nonimmediate threat like perceived jeopardy related to social situations, insecurity, uncertainty, and physical danger (Schwenkmezger & Steffgen, 1989). Physiologically, anxiety is associated with increased heart rate, increased skin conductance, increased rate of breathing, and dilated pupils (Kreibig, 2010; Levenson, 1992; Romero & Butler, 2007; Russell, 1980). These physiological changes are often evaluated as negative and are thought to lead to behaviors aimed at avoiding future anxious states (Öhman, 2008).

Research on the influence of anxiety on perception and action (e.g., swinging a bat, putting, throwing, or shooting a basketball) mostly shows that anxiety often leads to decrements in performance (Hardy & Parfitt, 1991; Higuchi, 2000; Nieuwenhuys et al., 2008; Pijpers, Oudejans, & Bakker, 2005; Pijpers, Oudejans, Bakker, & Beek, 2006). For example, Oudejans and colleagues investigated the influence of anxiety on climbing performance (Nieuwenhuys et al., 2008; Pijpers et al., 2006; Pijpers et al., 2005). Climbing consisted of making a series of reaches and grasps to holds while horizontally traversing a climbing wall. Anxiety was altered by having participants traverse either a high or low height (with higher heights presumed to evoke greater anxiety). They found that perceived and actual maximum reaches were decreased when participants were climbing at higher heights, and that anxiety was also greater at those heights. In addition, participants at higher heights moved more slowly, searched less, and noticed fewer distractor lights placed around holds.

Further, Hasegawa, Koyama, and Inomata (2013) investigated the influence of pressure to perform (which causes anxiety) on golf putting performance. Participants under high pressure and with high trait levels of anxiety performed worse than those not under pressure. Pressure to perform was induced via both an audience and monetary award. Detriments in performance under pressure were attributed to shortening of the back swing and decreasing downswing velocity. Similarly, Higuchi (2000) had participants throw balls underhanded to a target location and measured the release point of the throw, the variability of joint coordination across the throwing arm, and the accuracy of throws. Stress (a precursor to anxiety) was induced by emphasizing the accuracy of the task. Stress induction caused participants to stabilize their release point to the detriment of joint coordination and task accuracy.

On the other hand, task performance has also been shown to stabilize when anxiety is induced, despite potential deficits in

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motor coordination and attentional inefficiency. For example, Higuchi et al. (2002) investigated the influence of anxiety on swinging a baseball bat. They found that anxious participants' initiation of movement was delayed and amplitude of movement was decreased, but performance was more consistent across trials. Likewise, Nourrit et al. (2003) observed expert skiers in a skiing simulator under normal and stressful circumstances (the simulator was high off of the ground and thus skiing was more dangerous). Skiers displayed lower movement amplitude when skiing under anxiety-provoking circumstances, but their overall performance was unaffected.

All of the effects of anxiety on performance appear consistent with a dynamical systems perspective on motor control, which would treat anxiety as a variable (termed a control parameter) that affects one's pattern of movements used to perform a given task (Kelso, 1995). Changes in patterns of behavior might have a positive, negative, or negligible effect on task performance (e.g., accuracy). In the current task, we were particularly interested in the influence of anxiety on perceptual-motor calibration. Further, the behavior or a dynamical system is particularly dependent on task constraints, such as the ways in which movements can be executed or the amount of time to respond. Thus, we test the influence of anxiety on perceptual-motor calibration in tasks with different visual and motor constraints (discrete response and continuous modulation tasks), which further allowed us to explore the dynamics of behaviors within and between trials. In the current study, we manipulated these variables within a visually guided braking task that is discussed in more detail in the next section.

Perceptual-Motor Calibration in Braking to Avoid Collisions

Visually guided braking to avoid collisions is a useful task for testing the influence of anxiety on behavioral dynamics because there are formal descriptions of both the information and the actions for successful performance in the task. In this task, participants sped toward a series of stop signs on a TV monitor and had to decelerate so that they came to a stop as near as possible to the signs without passing through or beyond them. Lee (1976) proposed that visually guided braking to avoid collisions is accomplished by detecting an optical variable that specifies time-to-contact (τ) (see Eq. 1). The time derivative of this variable ($\dot{\tau}$) specifies the deceleration required to break before colliding with the object. By keeping deceleration under a critical value ($\dot{\tau} < -0.5$), the dynamic position of the organism can be controlled in relation to the environment to accomplish the goal of the task (i.e., avoiding collision).

$$\tau = \frac{\alpha}{\dot{\alpha}}, \tag{1}$$

where τ is the time-to-contact, α is an object's visual angle and $\ddot{\alpha}$is the visual angle's rate of change.

In the case of visually guided braking, the driver needs to adjust the braking pressure required to decelerate in enough time to avoid a collision. The driver must accomplish this by detecting information that specifies the amount of deceleration required to stop before colliding with an object by nulling the difference between current deceleration and the ideal amount of deceleration to stop on time ($\dot{\tau}< -.05$). As a matter of fact, the difference between $\dot{\tau} < -.05$ and current deceleration is available optically as an information variable called ideal deceleration (D_{Ideal}) and is given by Eq. 2. The use of this information variable has been observed in a number of motor control tasks, including braking (Kim & Turvey, 1999; McBeath, Shaffer, & Kaiser, 1995; Peper, Bootsma, Mestre, & Bakker, 1994; Wann & Land, 2000; Warren & Wertheim, 2014).

$$D_{Ideal} = \frac{v^2}{2z}, \tag{2}$$

where v is velocity, z is the target distance, and z/v is equal to the time-to-contact in Eq. 1, expressed in classic physical terms rather than optical terms. The ratio of speed and distance in Equation 2 is equivalent to the ratio of visual angle and change in visual angle in Equation 1. In other words, by continuously detecting D_{Ideal} participants can know how much deceleration (e.g., braking) is necessary to avoid a collision.

While D_{Ideal} is specified, the relationship between changes in deceleration and changes in brake application by the driver (i.e., the strength of the brake) is not. For example, two instances of braking might require a different amount of pressure applied to achieve the same amount of deceleration. D_{Ideal} does not capture this aspect of scaling. Fajen, 2005a, 2007) accounted for this issue by proposing *affordance-based control*, which suggests that information for controlling actions is scaled to action capabilities. In the case of visually guided action, D_{Ideal} is scaled to the maximum braking pressure that can be applied (D_{Max}). Thus, the units of D_{Ideal} are determined by the *action boundary* of D_{Max}, or the boundary between possible and impossible actions. Fajen (2005a) found that participants brake to keep $D_{Ideal} < D_{Max}$, which makes braking to avoid a collision possible (see Figure 1). When $D_{Ideal} > D_{Max}$, a crash is imminent. D_{Ideal} specifies the exact amount of deceleration necessary to stop at a given location. We will adopt this model, though it is still being validated (see Fajen, 2007).[1]

Fajen's work highlights the fact that detecting visual information is necessary but insufficient for successful action. For adaptive behavior to emerge in a task, actions must be effectively scaled to the requisite information

[1]A number of studies show that braking behavior is regulated with respect to D_{ideal}. Nonetheless, even if there are individual differences in the information variable that is detected, they are likely confounded in this task, because we did not experimentally manipulate some visual information (e.g., the optic flow or the eye height, cf. Fajen, 2005a).

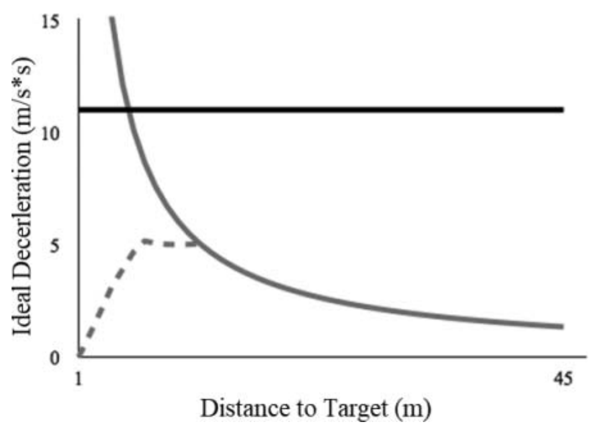


FIGURE 1. The relationship between D_{Ideal} and distance to the target is displayed. Without applying any braking pressure (solid gray line), D_{Ideal} increases exponentially as one approaches the desired stopping location. If the D_{Ideal} ever exceeds D_{Max} (solid black line), a crash is guaranteed to occur. If sufficient braking pressure is applied before reaching maximum deceleration, the car's speed will decelerate, and D_{Ideal} will decrease (dotted gray line). Thus, people need to brake so that D_{Ideal} remains below D_{Max} and eventually reaches 0 (meaning the car has stopped).

(Withagen & Michaels, 2007). In other words, perception and action must be effectively *calibrated*. In the case of braking, optical information (D_{Ideal}) must be scaled to the actual braking pressure applied (D_{Actual}) in order to avoid collisions. Numerous studies have shown that perceptual-motor calibration can be rescaled or disrupted, even in tasks as basic as walking (Abeele & Bock, 2003; Bingham & Pagano, 1998; Bruggeman & Warren, 2010; Bingham, Pan, & Mon-Williams, 2014; Pan, Coats, & Bingham, 2014; Pick, Wagner, Rieser, & Garing, 1999; Rieser, Pick, Ashmead, & Garing, 1995; Withagen & Michaels, 2002). With respect to braking to avoid a collision, Fajen (2005b) found that braking behavior quickly recalibrated to differences in brake strength. In addition, manipulations of optical information predictably recalibrated braking behavior. For example, increasing global optic flow rate led to overestimations of D_{Ideal} and quicker brake onset.

While Fajen and colleagues' work has provided perceptual-motor descriptions of visually guided braking, the change in braking behavior over time has not received much attention to our knowledge. Studying how perceptual-motor calibration evolves across multiple timescales would help to better understand the role that emotions such as anxiety have in perception-action tasks. In this study, we examine the influence of anxiety on perceptual-motor calibration, and thus, the influence of anxiety on task performance. In Nonlinear dynamic systems, small changes in an independent variable can have drastic consequences for coordinated patterns of behavior through time (cf. Warren, 2006). In fact, Brymer and Davids (2013) suggest that behavioral dynamics are influenced by individual constraints, environmental constraints, and task constraints. The combination of these constraints can produce an indefinite number of behavioral patterns, that are either functional or not, in any given task context. Because the past literature reliably demonstrates an effect of anxiety on both motor coordination and visual attention, but not necessarily task performance, we expected anxiety to influence the perceptual-motor calibration in a braking task. However, because of the dynamic nature of the task, the effect could vary within trials, across trials, and across tasks (continuous and discrete response tasks).

The Current Study

The braking-to-avoid-collision paradigm offers an opportunity to study the influence of anxiety on perceptual-motor calibration in a task in which the perceptual information and the requisite actions are known, measurable, and can be tightly controlled. We examined the online control of braking in two visually guided braking tasks, testing whether perceptual-motor calibration varied within trials, across trials, and across tasks with the induction of anxiety (cf. Fajen, 2005c). Participants performed a discrete braking task (Experiment 1) in which the application of braking pressure caused participants to come to a complete stop immediately and a continuous braking task (Experiment 2) in which braking could be continuously modulated within a trial.

This methodology allowed us to (1) probe the between-trial (Experiment 1), within-trial (Experiment 2), and between-task dynamics of perceptual-motor calibration and test whether this calibration is disrupted by inducing anxiety and (2) more precisely control and measure visual information and action over time. Studying these factors over time helps to capture the dynamic nature of anxiety's influence on task performance (Hardy & Parfitt, 1991; Warren, Sprott, & Hawkins, 2002).

In the discrete braking task, we expected that action (actual deceleration: D_{Actual}) would be scaled more sensitively to perceptual information (D_{Ideal}), such that braking would be initiated at higher values of D_{Ideal}. In other words, there would be a tighter coupling between perception and action. This is consistent with much of the research on anxiety and motor control, which demonstrates that movements tend to have lower amplitudes and are generally more cautious when one is anxious. Although this relationship between anxiety and task performance tends to depend on the task, cautious behavior in the discrete braking task (tested in Experiment 1) would lead to fewer crashes. Thus, performance on the discrete braking task may be improved by anxiety induction. In the continuous braking task, the predictions are less clear. Cautious braking might not lead to greater stopping distance, because changes in action that occur in relation to changes in visual information might lead to errors in braking that could compound within-trial. Furthermore, the continuous braking task is more difficult and requires fine-tuned movements that are not necessary for the discrete braking task. Thus, inefficiencies in attention and movement, often observed when anxiety is induced, might be more disruptive to task performance when observers have to continually adjust braking pressure.

Experiment 1: Discrete Braking

In the first experiment, participants were asked to brake (using a joystick) as close to stop signs (displayed on a large screen in a desktop virtual environment) as possible without crashing through them. Braking was performed by initiating braking without the ability to decrease deceleration once the brake was initiated. Thus, to complete this task, participants only needed to decide when to initiate braking. Anxiety was manipulated between-participants using a restricted breathing task (Graydon, Linkenauger, Teachman, & Proffitt, 2012; Hofmann, Bufka, & Barlow, 1999). Feedback was provided at the completion of each trial. We assessed the influence of anxiety on discrete braking performance and the dynamic influence of anxiety on perceptual-motor calibration across trials, particularly with respect to whether or not participants had crashed on the previous trial.

Method

Participants

Thirty-nine students (19 male, 20 female) from the University of Utah participated in this experiment for psychology course credit. Nineteen (11 male, 8 female) were assigned to the big straw condition (nonanxious) and 20 (8 male, 12 female) to the little straw condition (anxious). The average age was 23.2 ($SD = 4.06$) in the control condition and 23.0 ($SD = 6.63$) in the anxiety condition. Ages were not different between experimental groups ($t = .12$, $df = 36.6$, $p = .90$). All participants gave informed consent, were naïve to the purpose of the experiment, and had normal or corrected-to-normal vision.

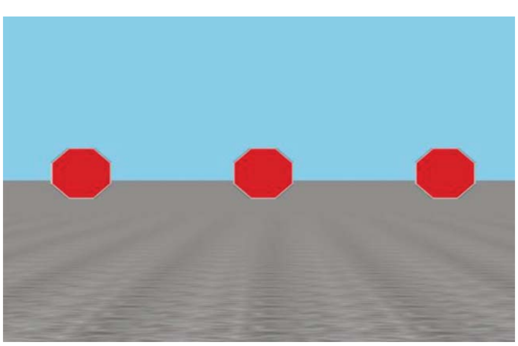


FIGURE 2. Participants viewed the above stimuli.

Displays and Apparatus

The simulated braking task was programmed using Python version 3.4.1. The program was implemented and the visuals generated using Vizard software, which was run on a computer with two Intel Core i7 2.93 GHz processors and Windows 7 SP 1.0 as its operating system. The computer was connected to a 60 in Samsung LED 3D-capable SmartTV using an HDMI connection. Stereo was not enabled. The display was updated at a frame rate of 60 Hz. The display was located 1.07 m from the chair where participants sat during the duration of the experiment. The height of the chair was adjusted so that participants viewed the display at a 1.1 m eye height from the center of the display.

The experimental stimuli were constructed to replicate Fajen's (2005a, 2005b, 2005c) previous studies of visually guided braking behavior. Observers viewed simulated movement along a linear path toward three red-and-white octagonal stop signs (see Figure 2). The sky was a shade of light blue, and the ground was composed of a gray, stone-like texture tiled throughout the world. The virtual environment was rendered with a simulated eye height of 1.1 m to match observers' seated positions. One stop sign was placed directly in the observer's simulated path of motion. The other two signs were placed directly to the right and the left of the observer's simulated path of motion. The distance between the edges of each stop sign was four times the radii of the signs.

Participants controlled braking pressure using a Logitech Extreme 3D Pro joystick. Participants initiated deceleration by pulling backward on the joystick from the neutral center. Deceleration was programmed to occur at a constant -11 m/s^2 as soon as the joystick was pulled back. A crashing noise was played on two Harmon-Kardon (CN-04N567-48220) external PC speakers if participants crashed through the visible stop sign on the screen.

Design and Procedure

After consenting, participants were instructed on the braking task. They were told that the goal of the task was to stop as close to the stop signs as possible without crashing through them. These instructions were meant to encourage participants to brake as they would in the real world in the event of an emergency (i.e., not braking 100 m before a stop sign or as soon as the trial began).[2] To initiate braking, they were told to pull back on the joystick. Further, they were informed that any movement backward on the joystick would result in maximal braking pressure (as if they had slammed on the brakes)

[2]Although participants' were instructed that braking would be similar to emergency braking, in the sense that pulling trigger would be like slamming on the brakes, the most important aspect of the instructions was to stop as close as possible to the stop sign. Based on observations of participants, it seems clear that they followed these instructions.

and that they would not be able to accelerate or decrease braking pressure once the joystick was pulled back.

Before the beginning of a trial, participants viewed a blank screen. When ready, participants initiated the trial by pushing the trigger button on the joystick, which they held with their dominant hand. Initiating the trial revealed the virtual environment in which the size of the stop signs (.165, .390, and .615 m radius) and initial velocity (8, 11, 14, 17, and 20 m/s) were manipulated within-subjects. Initial distance was held constant at 45 m from the stop signs τ was therefore 5.6, 4.1, 3.2, 2.6, and 2.3 s for each initial velocity, respectively). Varying sign radius and initial velocity was consistent with previous work (Fajen, 2005a), and prevented participants from adopting a braking strategy based purely on timing of the trials.

Participants performed the braking task for 75 trials (5 initial velocities $\times$ 3 sign sizes $\times$ 6 exposures) before the manipulation of anxiety was induced. This first set of trials familiarized participants with the task and allowed them to learn their D_{Max} (Fajen, 2005b). After anxiety induction, participants performed another 75 experimental trials for a total of 150 trials. The presentation of velocity and sign size was independently randomized for the practice and experimental trials. Participants took a short 30 s break after every 25 practice trials.

Before every 25 experimental trials, participants' level of anxiety was manipulated between-participants by either breathing through a little straw (coffee-stirrer sized; 2 mm) or a big straw (normal sized; 8 mm). Participants were instructed to breathe through either the big or little straw for at least 2 min before each block of 25 experimental trials. To measure changes in anxiety, participants indicated their distress from 0 to 100 (0 = calm enough to fall asleep; 100 = feeling as if they may have a panic attack) on the Subjective Units of Distress scale (Morgan et al., 2002). However, because breathing through a coffee-stirrer sized straw is extremely difficult, participants were allowed to stop breathing through the straw sooner than 2 min if needed.[3] Participants repeated the breathing task every 25 trials to ensure that their level of anxiety was raised for the duration of the experiment. The braking task ended after participants had completed all 75 experimental trials.

Immediately prior to and during each block of 25 trials, participants were asked to self-report level of anxiety using the SUDs scale, which consisted of a 0–100 scale. During the experimental trials, participants also self-reported level of anxiety before completing the breathing manipulation so that we could later calculate the change in SUDs level reported after the breathing task as a manipulation check for increases in anxiety in the small straw condition.[4] Participants were then debriefed about the nature of the experiment. The entire experiment lasted about 45 min.

Data Analysis

The results of the current experiment are presented in two sections. First, we analyzed whether successful performance of braking was altered by anxiety. Given that the instructions were to stop as close to the signs as possible without crashing, successful performance was determined by whether participants crashed or not (i.e., probability of crashing). If final stopping distance on a given trial occurred beyond the stop signs, then that trial was recorded as a "crash"—alternatively, that trial was recorded as "safe" if participants successfully braked in front of the stop signs. Variants of this measure have been evaluated in previous research (Fajen, 2005, 2005ab, 2005c; 2008).

Next, we utilized a multilevel, dynamical systems model (Butner, Gagnon, Geuss, Lessard, & Story, 2014). This model allowed us to investigate how earlier values of D_{Ideal} may have influenced changes in D_{Ideal} over time. Specifically, we determined, on every trial, the D_{Ideal} at which participants initiated braking. We then calculated the first derivative across trials to capture changes in behavior.[5] By regressing changes in braking behavior onto braking behavior, we ascertained both the value of D_{Ideal} where participants no longer changed their behavior and how participants adjusted braking behavior based on D_{Ideal}. Although D_{Ideal} is the visual information, its changes also represent how D_{Ideal} influences changes in D_{Actual}, since D_{Ideal} changes with D_{Actual}. We then analyzed changes in this D_{Ideal} across trials and as a function of anxiety condition. Multi-level models (MLM) were fit to the data using the lavaan package in R with restricted maximum likelihood estimation. Multilevel modeling is a generalized form of linear regression that is used to analyze variance in experimental outcomes predicted by both individual (within-participants) and group (between-participants) variables.[6] We

[3]All participants in the control (big straw) condition were able to breathe through the straw for the full 2 min. In the anxiety (little straw) condition, participants were able to breathe through the straw for an average of 58.2 s ($SD = 34.77$ s). There was no correlation between average time breathing through the straw and change in SUDs ratings from before to after breathing through the straw ($r = 0.011$, $p = 0.960$) suggesting that the manipulation of anxiety did not differ across participants who spent more or less time breathing through the straw.

[4]The use of the breathing task and the SUDS scale made it possible for participants to guess the purpose of the experiment (or at least that our manipulations involved testing anxiety). We did not ask participants whether they intuited our hypotheses; however, the breathing and SUDS scale were used in both anxiety conditions in both experiments, so the presence of demand characteristics should have equally affected both conditions, in similar directions across both experiments, if it did have an effect.

[5]The first derivative of D_{Ideal} was created using a single lag toeplitz design and averaging across lags using the GOLD method (Deboeck, 2010). A single lag was used as Average Mutual Information indicated that this was the smallest lag not influenced by autocorrelations (Hausser & Strimmer, 2009).

[6]A MLM was appropriate for modeling our data and testing our hypotheses for two major reasons: (1) MLM allows for the inclusion of interactions between continuous variables (in our case, visual information variables) and categorical variables (in our case, anxiety condition); (2) MLM uses robust estimation procedures appropriate for partitioning variance and error structures in mixed and nested designs (repeated measures nested within individuals in this case), including modeling interaction variables across levels.

describe each of the models used prior to explanation of the results.

Results

Manipulation Check

To test whether participants in the anxiety condition were more anxious, anxiety scores were created for each participant by averaging across the SUDs ratings recorded before the breathing task and subtracting it from the average scores obtained after the breathing task. An independent samples *t* test with condition (little or big straw) as the between-participants factor revealed that participants in the little straw condition showed a larger change in SUDs ($M = 9.12$) than participants in the big straw condition ($M = -3.37$), $t(37) = -3.83$, CI_{95} [−19.09, −5.88], $p < .001$. These findings suggest that participants in the anxiety condition (little straw) experienced a larger increase in anxiety than participants in the control condition (big straw) after the breathing manipulation.

Probability of Crashing

To assess whether the probability of crashing changed as a function of condition, we performed a multi-level logistic regression using the following model:

Level 1 of our multilevel model is given by Eqs. 3–7:

$$Logit\ (Crash)_{ij} = \beta_{0j} + \beta_{1j} * (Size) + \beta_{2j} * (Velocity) + \beta_{3j} * (Size * Velocity) + r_{ij}, \quad (3)$$

and level 2 by:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} * (Condition) + \gamma_{02} * (Velocity) + \gamma_{03} * (Size * Velocity) + u0_j, \quad (4)$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} * (Anxiety\ Condition) + u1_j, \quad (5)$$

$$\beta_{2j} = \gamma_{20} + \gamma_{21} * (Anxiety\ Condition) + u2_j, \quad (6)$$

$$\beta_{3j} = \gamma_{30} + \gamma_{31} * (Anxiety\ Condition) + u3_j, \quad (7)$$

Where i represents trials, j represents individuals, and the β and γ terms are the regression coefficients. The error term r_{ij} indicates the variance in the outcome variable on a per trial basis, and $u0j$ on a per person basis (Raudenbush & Bryk, 2002). Participant was entered as a random factor to account for the fact that each participant performed multiple judgments. Crash was coded such that a 0 indicated a successful stop and a 1 indicated a crash. Condition was coded such that the control (big straw) condition was 0 and anxiety (little straw) condition was a 1. Both size and velocity were centered at their means. Although it is assumed that people differ, on average, ($u0j$) in the outcome variable, we tested whether the effect of crash differed per person ($u1j$) using a variance-covariance components test. Using a chi-squared difference of fit test, we found that the model that included a random effect of anxiety fit the data better than the model that did not include this effect, so the current results reflect the model with the random effect ($\chi^2 = 955.95$, $df = 2$, $p < 0.001$). Including this term allowed us to differentiate between the variance accounted for in change in braking specific to a fixed effect of anxiety and the variance accounted for in change in braking specific to a random effect of individual differences across people.

There were main effects of both size of the target ($\gamma_{10} = -1.524$, $SE = 0.514$, CI_{95} [−2.5323, −0.5163], $p = 0.003$) and velocity ($\gamma_{20} = 0.234$, $SE = 0.022$, CI_{95} [0.189, 0.278], $p < 0.001$). Increases in the size of the target were associated with a reduced probability of crashing. This result replicates previous work (cf., Fajen, 2008). Increases in initial velocity were associated with increases in probability of crashing. This result was expected because the τ decreased as velocity increased. The analyses revealed a trend toward an effect of condition ($\gamma_{01} = -0.422$, $SE = 0.233$, CI_{95} [−0.8782, 0.0337], $p = 0.069$) suggesting that participants in the anxiety condition had a lower probability of crashing, but this effect did not reach significance.

The trending effect of condition was moderated by a significant interaction between condition and velocity, $\gamma_{21} = 0.070$, $SE = 0.035$, CI_{95} [0.0003, 0.1387], $p = 0.048$. Analyses of simple slopes revealed a significant effect of condition at slower velocities (centered at 8 m/s), $\gamma_{01} = -0.839$, $SE = 0.376$, CI_{95} [−1.5779, −0.1008], $p = 0.030$ (see Figure 3). There was also a significant interaction between condition and size, $\gamma_{11} = -1.837$, $SE = 0.833$, CI_{95} [−3.470, −−0.2052], $p = 0.027$. Analyses of simple slopes revealed a significant effect of condition at larger sized signs (0.69 m radius), $\gamma_{01} = -0.836$, $SE = 0.333$, CI_{95} [−1.4884, −0.1830], $p = 0.010$.

At slower velocities, participants in the anxiety condition were less likely to crash (1.65%) than participants in the control condition (3.75%). At larger sized signs, participants in the anxiety condition were less likely to crash (10.08%) than participants in the control condition (4.64%). Under these conditions, anxiety approximately halved the probability of crashing. There was a non-significant influence of condition at faster velocities (centered at 20 m/s) and at smaller sized signs ($p > 0.050$). There was a nonsignificant interaction between size, velocity, and condition, $\gamma_{31} = 0.224$, $p > 0.100$.

Perceptual-Motor Calibration between Braking Events

Changes in braking behavior across trials were analyzed in the following multilevel linear model:

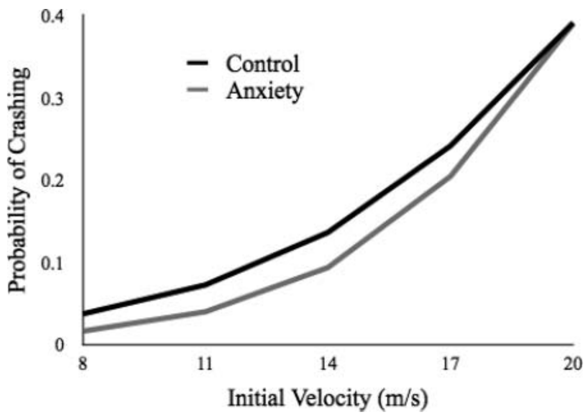


FIGURE 3. Probability of crashing for the anxiety (gray line) and control (black line) are plotted for each of the initial velocities. Participants in the anxiety condition crashed less often than participants in the control condition at lower velocities. Values plotted are model fit after controlling for all other independent variables.

Level 1 of our multilevel model is given by Eqs. 8–10:

$$\Delta D_{Idealij} = \beta_{0j} + \beta_{1j} * (D_{Idealij}) + r_{ij}, \tag{8}$$

and level 2 by:

$$\beta_{0j} = \gamma_{00} + \gamma_{01} * (Anxiety\ Condition) + u_{0j}, \tag{10}$$

$$\beta_{1j} = \gamma_{10} + \gamma_{11} * (Anxiety\ Condition) + u_{1j}, \tag{11}$$

where i indexes trial-level variations in the D_{Ideal} at the initiation of the discrete brake and j indexes participants. Participant was entered as a random factor on the intercept, size of the target, and initial velocity to account for the dependencies of participants, size of target, and initial velocity. Condition was coded such that the control condition was 0 and the anxiety condition was 1. Affordance was centered on 11 (D_{Max}), because this value represents the critical boundary between successfully stopping and crashing. A negative γ_{1j} indicates that participants made adjustments toward using a specific value of D_{Ideal} to initiate braking. We used D_{Ideal} instead of time of brake initiation because we were specifically interested in how braking behavior was regulated with respect to visual information. Furthermore, time of brake initiation does not reliably correspond to τ (see Fajen, 2005a).

The analysis revealed a significant influence of D_{Ideal} on changes in D_{Ideal}, $\gamma_{10} = -.2333$, $SE = 0.008$, CI_{95} [−0.248, −0.218], indicating that participants made trial-to-trial adjustments based on D_{Ideal}. By setting change to 0 and solving for x, we determined the value of D_{Ideal} at which braking was initiated for each group. Anxious participants initiated braking at lower D_{Ideal} ($M = 7.56$ m/s^2) than participants in the control condition ($M = 8.15$ m/s^2). How sensitive (changing actual braking as a function of ideal braking) participants were to changes in D_{Ideal} is represented by γ_{1j}. Larger (more negative) values of γ_{1j} indicate that participants made more drastic adjustments from trial-to-trial (see Butner et al., 2014 for more information on using derivatives as outcomes). There was no significant interaction between condition and D_{Ideal}. However, there was a main effect of condition, $\gamma_{01} = -0.1789$, $SE = 0.084$, CI_{95} [−0.343, −0.015] (see Figure 4). At D_{Max}, anxious participants exhibited larger negative adjustments than control participants—suggesting that anxious participants' perceptual-motor calibration became more tightly coupled on trials following a crash.

Our results revealed that over trials, participants from both conditions made adjustments in braking to reside in a safe area ($D_{Ideal} < D_{Max}$) suggesting that all participants were sensitive to the conditions of success. Relevant to the goal of the current study, anxious participants made more drastic adjustments than control participants following a crash. That is, following a crash, anxious participants braked at reduced D_{Ideal} to a greater extent than control participants on subsequent trials. In other words, participants who are anxious are not just braking sooner. If they were just braking sooner, the two lines in the graph would be parallel. The fact that there are different slopes in the two lines suggests that anxious participants are braking sooner but only *after* negative consequences.

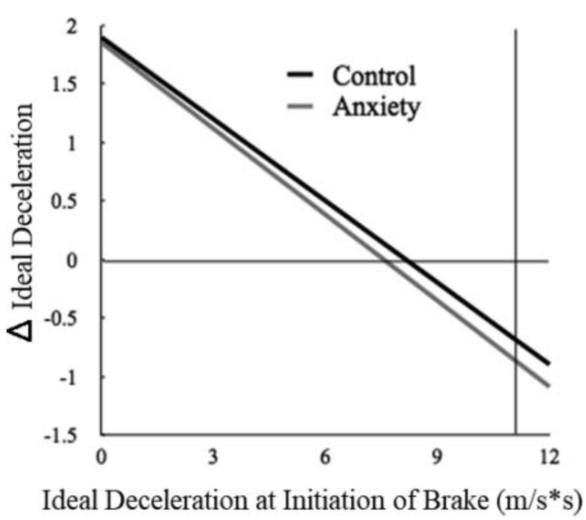


FIGURE 4. Change in when participants initiated braking pressure, in terms of D_{Ideal}, from trial-to-trial is plotted against D_{Ideal} on current trial for no anxiety (black line) and anxiety (gray line) conditions. A negatively sloped line indicates that participants in both conditions adjusted braking pressure across trials toward an attractive point (where each line intersects with zero change). A vertical line is placed at the D_{Max} (11 m/s^2). After trials in which participants crashed (values right of the vertical line), anxious participants initiated brakes significantly sooner. Values plotted are model fits after controlling for all other independent variables.

Discussion

In Experiment 1, anxious participants crashed less often than control participants, particularly at lower initial velocities. We also observed trial-to-trial variations in braking behavior, in which anxious participants responded more drastically to crashing on the previous trial by initiating braking at a lower D_{Ideal} on subsequent trials. Interestingly, anxious participants did not just brake earlier on every trial, but rather braked earlier only after crashing (as evidenced by the different slopes in Figure 4). This suggests that differences in overall braking performance, in terms of a reduction of crashes, could be due to anxiety influencing how D_{actual} was calibrated to D_{Ideal} across trials. Specifically, D_{Actual} was more sensitive to changes in D_{Ideal}. Thus, in a discrete braking task, anxiety led to more sensitive calibration between perception and action, which resulted in fewer crashes, because participant's reacted by becoming more cautious after crashes on previous trials.

Experiment 2: Continuous Braking

In Experiment 2, we tested how anxiety influences performance in a within-trial perception-action calibration task that required continuous adjustment of action. In contrast to Experiment 1, braking pressure/deceleration could be continuously modulated while performing the task. The continuous braking paradigm allowed us to test a different task constraint, given that quicker reactions to changes in D_{Ideal} would necessitate greater compensatory braking later in the trial. Answering this question will help to inform how anxiety influences perceptual-motor calibration over time, specifically testing whether its influence differs based on nature of the scaling between perception and action required for the task and the difficulty of the task.

Method

Participants

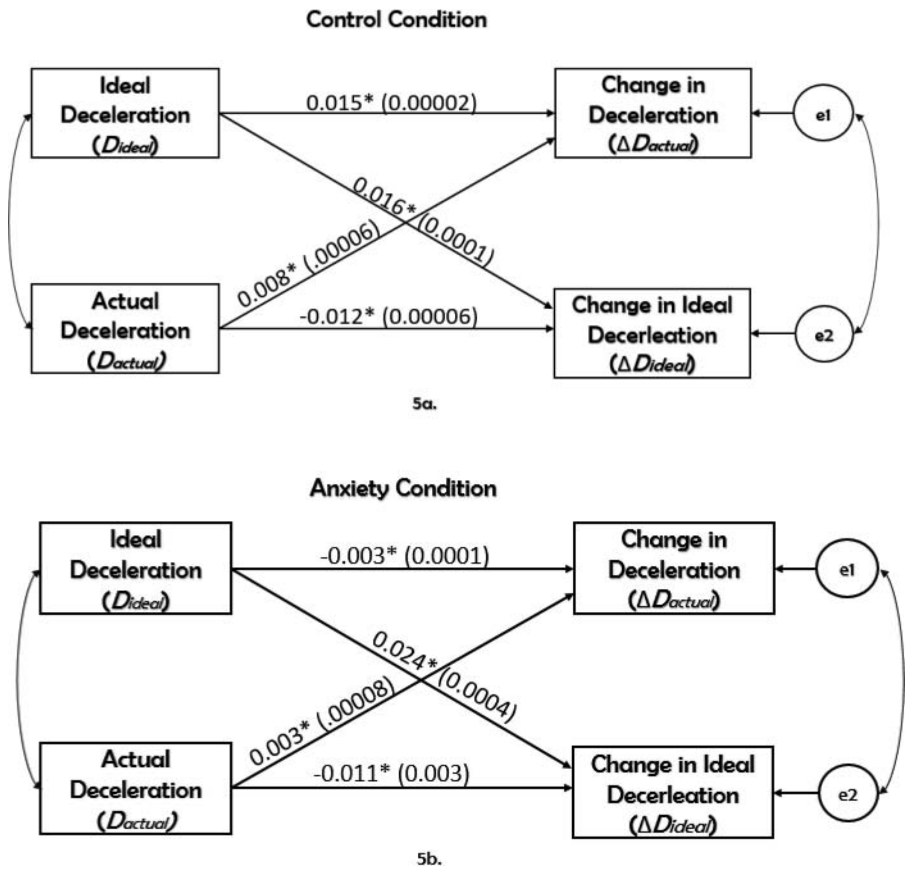
Forty-two students (17 male, 25 female) from the University of Utah participated in this experiment for psychology course credit. Twenty-one (7 male, 14 female) were assigned to the control (big straw) condition and 21 (10 male, 11 female) to the anxiety (little straw) condition. The average age was 21.6 ($SD = 3.59$) in the control condition and 22.5 ($SD = 4.2$) in the anxiety condition. Ages were not different between experimental groups ($t = -0.6$, $df = 21.99$, $p = .53$). All participants gave informed consent, were naïve to the purpose of the experiment, and had normal or corrected-to-normal vision.

Design and Procedure

The design and procedure were similar to those used in Experiment 1, with two exceptions. First, deceleration was programmed to be linearly proportional to joystick position (no movement of the joystick was associated with 0 m/s^2 deceleration and full movement of the joystick with 11 m/s^2 deceleration). Instructions were modified to reflect the difference in braking control. Second, feedback was provided within trials. If braking deceleration exceeded 9.5 m/s^2, a tire-screeching noise was played to inform participants that they were braking near their maximum braking capability. This aspect of the procedure is consistent with Fajen (2008), and was used to discourage participants from waiting until the last possible moment to brake. Participants were told that pulling back farther on the joystick would result in proportionally more braking pressure. As in Experiment 1, participants were instructed that they should stop as close to the stop signs as possible without crashing through them. However, participants were permitted to adjust their braking behavior within-trials (apply more braking pressure or release braking pressure). The display of the stop signs and virtual desktop environment were the same as Experiment 1.

Data Analysis

To test the within-trial calibration between perception and action, we analyzed the influence of anxiety on the coordination between D_{Ideal} and D_{Actual} within trials. To model this relationship, we implemented an Actor-Partner Interdependence Model (APIM; Kashy & Kenny, 2000). In this analysis, changes in D_{Actual} and D_{Ideal} are simultaneously regressed on to the current value of both variables. Changes in D_{Actual} were calculated by taking the first derivative of current deceleration (recorded 60 times a second). Changes in D_{Ideal} were calculated by taking the first derivative of D_{Ideal} (calculated from velocity and distance, recorded 60 times a second). In the current data set, a lag of 12 was used as Average Mutual Information, which indicated that this was the smallest lag that could be used with these data with minimum influence of autocorrelations (Kantz & Schreiber, 1997). The first derivative of current deceleration was created using a 12 lagged toeplitz design and averaging across lags using the GOLD method (Deboeck, 2010). A lag of 12 data points is equivalent to averaging change over 200 ms. Therefore, change outcomes capture adjustments that occurred over a 200 ms window. This is the exact same window size used in previous research to analyze change in braking behavior (Fajen, 2005a). Positive values indicate that participants increased braking pressure and larger positive values indicate a quicker change in braking pressure (pulled back on the joystick harder and/or faster). Negative values indicate that participants 'let up' on the brakes. It is important to note that negative values do not indicate that participants accelerated because no acceleration was possible. Zero change indicates that participants held a constant braking pressure. Zero change points were included in the analysis as it is important to capture when participants also decided not to adjust the brake. For the 200 ms window, change in braking pressure was, on average, relatively small ($M = .0423$, $SD = .136$, range [−1.23, 1.29]. This allowed us



FIGURES 5a and 5b. Path diagrams of the Actor-Partner Interdependence Model (APIM). Anxiety condition was included in the model and allowed to interact with each of the regression slope parameters (single-headed arrows). Though the model was ran as a multilevel model, it is presented in this form for simplicity.

to probe the calibration between D_{Actual} and D_{Ideal} while controlling for current rate of deceleration (see Figure 5). Condition and the probability of crashing were included as second level moderators and were allowed to interact with the intercepts, partner, and actor effects.[7] Further, by adding condition as a second level variable, we investigated how anxiety altered the within-trial calibration between D_{Actual} and D_{Ideal}.

Results

Manipulation Check

An independent samples *t* test with condition (anxiety and control) as the between-subject factor revealed that participants in the anxiety condition had a larger positive change in SUDs ($M = 13.5$,) than participants in the control condition ($M = -1.13$) after breathing through the straw, $t(40) = -3.77$, CI_{95} [−22.47, −6.78], $p < 0.001$. Participants in the anxiety condition indicated a larger increase in anxiety than participants in the control condition. To test whether comparisons were appropriate across experiments, we used *t*-tests to determine whether the average change in SUDS throughout the experiment differed for each of the experimental conditions. Average change in SUDS was not different across experiments for the anxiety ($t = -.45$, $df = 39.69$, $p = .66$) or for the control ($t = 0.37$, $df = 37.92$, $p = .71$) groups.

Probability of Crashing

To assess whether condition had an influence on the performance of continuous braking, the same analyses that were ran in Experiment 1 were also ran here on the experimental trial block only. There were significant main effects of both size of the target ($\gamma_{10} = -1.168$, $SE = 0.544$, CI_{95} [−2.2334, −0.1023], $p = 0.030$) and velocity ($\gamma_{20} = 0.302$, $SE = 0.024$, CI_{95} [0.2556, 0.3489], $p < 0.001$). Increases in the size of the target were associated with a reduced

[7]Crash was coded such that 0 indicated a successful stop and 1 indicated a crash. Crash was included as a variable because the relationship among variables will necessarily differ when one does not apply enough braking force to stop. Condition was coded such that the control (big straw) condition was 0 and the anxiety (little straw) condition was 1.

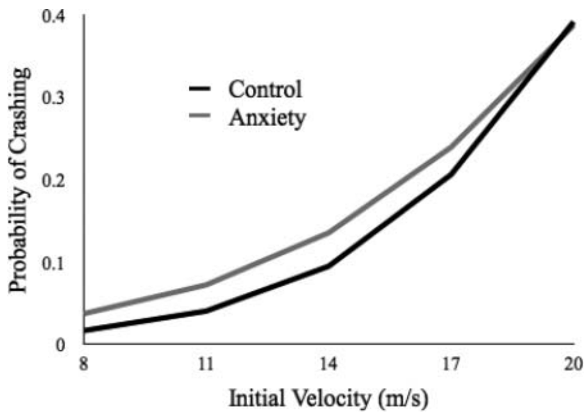


FIGURE 6. Probability of crashing for the anxiety (gray line) and control (black line) are plotted for each of the initial velocities. Participants in the anxiety condition crashed more often than participants in the control condition at lower velocities. Values plotted are model fit after controlling for all other independent variables.

probability of crashing. Increases in initial velocity were associated with increases in probability of crashing. These results are consistent with those found in Experiment 1 and in Fajen (2005a).

As in Experiment 1, there was a significant interaction between condition and velocity, $\gamma_{21} = -0.069$, $SE = 0.031$, CI_{95} [−0.1308, −0.0088], $p = 0.025$ (see Figure 6). Analyses of simple slopes revealed that there was a significant effect of condition at slower velocities (centered at 8 m/s), $\gamma_{01} = 0.820$, $SE = 0.395$, CI_{95} [0.0462, 1.594], $p = 0.030$. Anxious participants were more likely to crash than control participants at the slower velocities, but the effect of condition disappeared at higher velocities. At slower velocities, participants in the anxiety condition were *more* likely to crash (3.74%) than participants in the control condition (1.68%). The probability of crashing doubled when anxious. Unlike Experiment 1, there was a non-significant interaction between condition and size ($\gamma_{11} = 0.33$, $p = 0.640$).

Perceptual-Motor Calibration Between Braking Events

To investigate the influence of anxiety on across-trial adjustments, we performed the same analysis as in Experiment 1. Specifically, we determined the D_{Ideal} at which participants initiated braking for each trial. Change across trials in D_{Ideal} was regressed onto current D_{Ideal}, condition, and the interaction between D_{Ideal} and condition. The analysis revealed no significant influence of D_{Ideal} on changes in D_{Ideal}, no main effect of condition, and no interaction between D_{Ideal} and condition ($t < .6$) suggesting that participants did not alter the initiation of braking behavior across trials based on D_{Ideal} information or condition. The lack of an influence across trials may be due to the greater saliency of feedback provided within a given braking event.

Perceptual-Motor Calibration Within Braking Events

The results in this section are from the APIM model discussed above. For the control condition, we found a significant positive influence of current D_{Ideal} on changes in D_{Ideal}, $\gamma_{100} = .01576$, $SE = 0.00009$, CI_{95} [0.019557, 0.01595]. As D_{Ideal} increased, the rate of change in D_{Ideal}

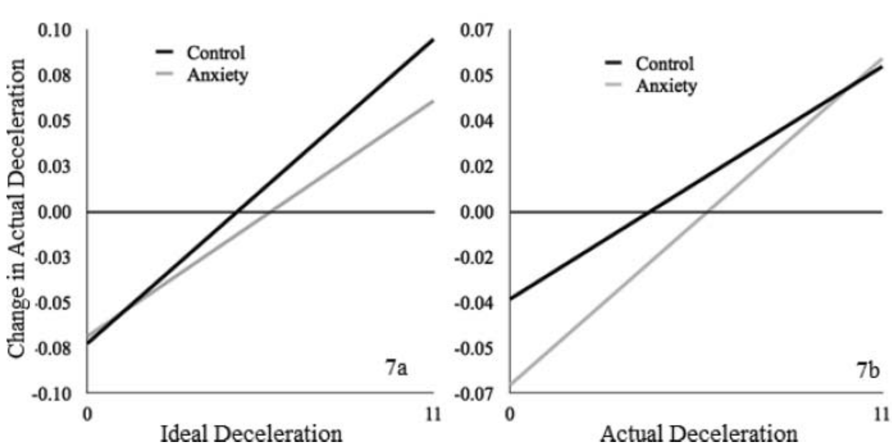


FIGURE 7. Graphs display differences in rate of change in D_{Actual} as a function of current D_{Ideal} (left, 7a) and of D_{Actual} (right, 7b) for control (black line) and anxious participants (gray line). Anxious participants used D_{Ideal} to adjust D_{Actual} less than control participants (7a). However, anxious participants used D_{Actual} to adjust D_{Actual} more than control participants (7b).

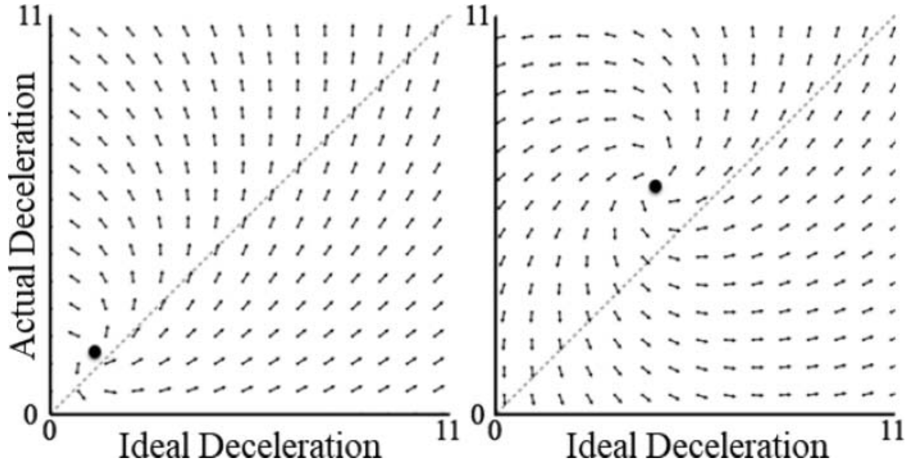


FIGURE 8. Phase portraits of D_{Actual} and D_{Ideal} state space. Results from the APIM analyzed on within-trial data from anxious participants (left) and control participants (right). D_{Ideal} is displayed on the X-axis and D_{Actual} on the Y-axis. Data within the graph indicates the direction of **change** in braking pressures within-trials. The 45 degree line separates the possible trajectories into behavior that is safer (above the 45 degree line; participants apply more braking pressure than necessary) and behavior that is more dangerous (below the 45 degree line; participants apply insufficient braking pressure). The dot within the graph indicates the repeller, or point of inflection, around which braking trajectories oscillated.

was larger. As D_{Actual} increased, the rate of change in D_{Ideal} was smaller, $\gamma_{200} = -0.01219$, $SE = 0.00006$, CI_{95} [−0.01231, −0.01207]. As expected, when participants applied more braking pressure, D_{Ideal} decreased. These results are expected given the nature of D_{Ideal} (see Figure 1).

As D_{Actual} increased, the rate of change in D_{Actual} was larger, $\gamma_{100} = 0.00814$, $SE = 0.00006$, CI_{95} [0.00802, 0.00825] indicating that the more braking pressure participants applied, the more braking pressure changed. In other words, changes in deceleration are higher at higher values of actual braking. As D_{Ideal} increased, the rate of change in braking pressure was larger, $\gamma_{200} = 0.01520$, $SE = 0.00002$, CI_{95} [0.01517, 0.01522] indicating that participants applied the brake faster at higher values of D_{Ideal}. This replicates previous findings from Fajen (2005a).

On average, anxious participants used less braking pressure ($\gamma_{001} = -0.01051$, $SE = 0.0029$, CI_{95} [−0.01621, −0.00481]) and allowed D_{Ideal} to reach higher values ($\gamma_{011} = 0.02366$, $SE = 0.0004$, CI_{95} [0.02288, 0.02444]) than controls. Anxious participants also adjusted D_{Actual} based on D_{Ideal} *less* than control participants, $\gamma_{201} = -0.00342$, $SE = 0.00014$, CI_{95} [−0.00369, −0.00315] (see Figure 7a). Anxious participants adjusted D_{Actual} based on current braking pressure *more* than control participants, $\gamma_{101} = 0.00329$, $SE = 0.00008$, CI_{95} [0.00312, 0.00345] (see Figure 7b).

The complete results from the APIM model are plotted as a phase portrait (Figure 8), which is a representation of how the patterns within the perceptual-motor state space change depending on the initial conditions of the system and is the model fit of *change* based on all within-trial braking trajectories (as shown in Figure 7). Differences between conditions can be seen in terms of the point of inflection (repeller) and how quickly participants increased D_{Actual} with regard to each axis. Any trajectory that intersects a value of 0 for D_{Ideal} indicates that participants stopped. Any trajectory that intersects a value of 11 for D_{Ideal} indicates that participants will crash. The 45 degree line separates the possible trajectories into behavior that is safer (above the 45 degree line) from where participants supply insufficient braking pressure (below the 45 degree line). Anxious participants oscillated around a lower point, applying less braking pressure, on average, than control participants. In addition, anxious participants' point of inflection was much closer to the 45 degree line, making it more difficult to react to changes in D_{Ideal}. These phase portraits suggest that the dynamics of braking within a braking event are less stable when anxious. Within-trial variation of braking behavior is more likely to move into the dangerous zone (near D_{Max}) below the 45 degree line, and therefore more likely to lead to a crash when anxious.

We ran a post-hoc comparison on value of D_{Ideal} at the initial onset of braking to test whether the difference in within-trial perceptual-motor calibration is specific to continuously regulating braking behavior. There was no difference between D_{Ideal} at the initial onset of braking for the control ($M = 5.47$) and anxious ($M = 4.97$) conditions, $t = 1.22$ $df = 39$, $p = 0.231$. Thus, even though the coupling between information and action for the anxious participants was weaker than controls, there was no difference between when participants in the two conditions initiated braking.

Discussion

When performing a continuous braking task, anxious participants crashed more often than controls. Anxious participants maintained lower D_{Actual} on average, as shown in Figure 8 with their lower inflection point. Interestingly, these braking dynamics for anxious participants led to less adaptive braking behavior (initial conditions were more likely to fall/remain under the 45 degree line in Figure 8). Anxious participants made *less drastic* braking adjustments based on changes in D_{Ideal} than control participants, indicating that they were less sensitive to changes in D_{Ideal}. It seems changes in their braking depended more on whether they had just decelerated at the previous time point. We also did not replicate the variation in trial-to-trial calibration in response to crashes observed in Experiment 1. This could be because continuous regulation of braking is too complex to be modulated across trials with feedback about crashing or that the feedback was insufficient for improving performance. It was much easier to simply brake at a greater ratio of D_{Ideal} and D_{Max} in Experiment 1 then it was to differentially regulate braking in Experiment 2 after crashing on the previous trial.

General Discussion

In the current study, we tested the influence of anxiety on perceptual-motor calibration while performing a common task: braking to avoid a collision. We adopted a dynamical systems approach to account for the mixed literature on this topic by considering both the context and timescale of performance. We hypothesized that anxiety would influence the relationship between perception (the detection of D_{Ideal}) and action (D_{Actual}), along with the performance of the task in ways that might depend crucially on the nature of the task and the timescale of measurement. Specifically, we were interested in the influence of anxiety on perception in tasks with different constraints (discrete response and continuous modulation tasks), which further allowed us to explore the dynamics of behaviors within- and between-trials using analytic techniques from dynamical systems theory. We expected that the discrete braking scenario would lead to more tightly coupled perceptual-motor calibration and thus fewer crashes. On the other hand, we suspected that tighter coupling between perception and action in the continuous braking scenario might lead to an increase in braking adjustments that would compound within-trials and lead to more crashes.

In both the discrete and continuous braking tasks, the perceptual-motor calibration was influenced by inducing anxiety. In the discrete braking task, participants crashed less often and action (D_{Actual}) and perception (D_{Ideal}) were more sensitively calibrated. This led to a quick response, and ultimately, fewer crashes, particularly at low initial velocities. This effect was intensified across trials for anxious participants who braked sooner when they crashed on previous trials. It is important to note that the results do not suggest that anxious participants adopted a general bias of just braking sooner on every trial. Rather, the anxiety served to specifically influence trials after a crash. In contrast, for the continuous braking task, the effect was reversed. Anxious participants in the continuous task crashed more often and the coupling between D_{actual} and D_{Ideal} was diminished. Thus, we found partial support for our hypothesis. Anxiety led to tighter calibration between perception and action (a conservative braking style) in the discrete braking task. But, anxiety led to a weaker coupling between perception and action in a continuous action task. It seems that the detriment in performance engendered by anxiety is specific to tasks in which behavior is adjusted continuously with variations in perceptual information. As Brymer and Davids (2013) suggested, small changes in the context of the task can significantly reorganize behavioral dynamics. The results suggest that the influence of anxiety on performance may depend on the nature of the task/action (continuous vs. discrete in the case of the current study) and that behavioral dynamics may be a useful method to understand the influence of state variables like emotion on performance.

We were also interested in between-group dynamics of perceptual-motor calibration in both tasks. In the discrete braking task, anxious participants made larger adjustments than controls following a trial with a crash. Changes in discrete braking following negative events were altered in a "safer" direction and to a larger degree when anxious. In the continuous braking task, the consequences of crashing did not affect braking adjustments between trials as they did in the discrete braking task. The lack of influence of crashing on continuous braking behavior could have been due to (1) the simpler constraints in the discrete braking task leading to a greater sensitivity to consequences, or (2) the inherent complexity of the task that necessitated more fine-tuned adjustments in braking in response to changes in visual information. It is possible that crashes might have influenced continuous braking in the same way as the discrete braking task with a different form of feedback and/or additional time to incorporate that feedback.

It is also possible that differences in attention between conditions and experiments could account for our results. We found that braking was more related to changes in the position of the controller itself than it was to changes in D_{Ideal} for anxious participants in the continuous braking task. This would be consistent with previous research that has shown, when anxious, participants attend more to procedural motor information and resulting performance suffers (Higuchi et al., 2002; Pijpers et al., 2006). Distraction theories of anxiety argue that performance deteriorates when under pressure because individuals divert their attention away from task-relevant information (Beilock & Carr, 2001; Lewis & Linder, 1997). For example, Beilock and Carr (2001) found that novice golfers encoded procedural aspects of golfing more explicitly than experts and that performance was ameliorated by devoting less attention to these aspects of putting. Our results are perhaps also consistent with previous work suggesting that anxiety leads to attentional lapses while driving (Shahar, 2009; Wong, Mahar, & Titchener, 2015). Anxious participants may have performed worse in the continuous action task because they attended to ineffective perceptual variables or because their attention dynamically shifted between perceptual variables. In addition, participants in the small-straw breathing condition might have become distracted in anticipation of the difficult breathing task in addition to their anxiety. On the other hand, our work focused on the relationship between perception and action and suggests that, rather than causing lapses in attention, anxiety might lead to a rescaling of perceptual-motor calibration. However, future work is needed to disentangle the complex relationship between attention and perceptual-motor calibration in the control of action over time.

Our results do have implications for the affordance-based control model of perception-action, which suggests that people control behavior with respect to boundaries of possible and impossible actions (Fajen, 2007). In braking to avoid collision, this theory posits that D_{Ideal} does not need to be controlled continuously. Drivers simply need to modulate their speed to keep $D_{Ideal} < D_{Max}$, which designates the boundary between being able to stop or not to avoid a collision. Because the error between D_{Ideal} and D_{actual} does not have to be continuously modulated, successful collision avoidance can be accomplished with different behavioral patterns. Harrison, Turvey, and Frank (2016) capture these variations in braking dynamics as "soft" constraints. Unlike "hard" constraints (which determine the action boundaries), soft constraints determine the particular trajectories taken during a braking event (e.g., a conservative vs. a liberal style of keeping D_{Ideal} below D_{Max}). Anxiety (or emotions more broadly) could be conceptualized as a soft constraint. However, since anxiety affected the probability of crashing and decoupled calibration in the continuous braking task, it is unlikely that it was a soft constraint in all task situations. Future work will be needed to determine how to successfully incorporate anxiety in affordance-based control models.

Limitations and Future Directions

The current study cannot determine whether changes in performance when anxious was due to consciously perceiving the world differently. Previous research has argued for a change in perceived size, distance, and judged capability when anxious or physiologically aroused (Geuss, Stefanucci, Creem-Regehr, & Thompson, 2010; Graydon et al., 2012). Did anxious participants in the current experiment consciously perceive the stop signs as larger or speeds as faster? This interpretation seems unlikely given the difference in the direction of effects across the two studies. If anxious participants saw speeds as a faster, for example, then they should have initiated braking sooner and crashed less often in both studies. The observed difference across studies suggests that changes in performance cannot be attributed to a unitary perceptual change when anxious. Rather, our results seem to suggest that performance of a braking task is influenced by anxiety through complex changes in perceptual-motor calibration over time.

Similarly, the results have implications for Witt and Riley's (2014) concept of the extended global array, which suggests that agents detect complex information that is structured across multiple energy arrays, including interoceptive arrays (senses that detect internal regulation responses like hunger). Thus, emotions can comprise a part of the information used to perceive and act (see also Storbeck & Clore, 2008). In this view, our results might suggest that interoception of anxiety becomes partial information for controlling braking to avoid collisions. Consistent with the above description, participants' experience of distances would actually change in this case. However, it seems more likely that anxiety influenced the coordination between D_{Actual} and D_{Ideal}. Nonetheless, we cannot make strong claims about whether changes in anxiety result in changes in perception in this task.

It is possible that the breathing task, along with the SUDS scale, created experimenter demand in the study, such that participants knew we were investigating anxiety and may have altered their responses accordingly. However, any demand characteristic would have been equally present across the two anxiety conditions, as well as across experiments, given that all participants completed both a straw-breathing task and SUDS. Furthermore, one might expect that SUDS scores in the big-straw (control) condition would not have been significantly lower than the small-straw condition if experimenter demand influenced participant's anxiety reports, as participants were unaware that the straw size differed between-subjects. Although we regret not directly asking participants if they were aware of the hypotheses in our experiments, we believe that the effects observed due to our manipulation were likely not solely due to demand characteristics. Specifically, we observed conflicting results across experiments, making it less likely that experimenter demands were prevalent. Why would one set of participants suspect that anxiety should change braking in one direction, but the participants in another experiment bias their responses in a different direction? We are unable to explain this change in the direction of observed results across experiments with experimenter demand. Further, if there was experimenter demand, we would expect it to remain consistent across trials given participants knew we were still testing for anxiety. However, we observed changes in braking from trial to trial that are more consistent with a waning manipulation than a consistent behavioral pattern that indicates the use of a strategy to comply with a hypothesis. Nonetheless, it is possible that experimenter demand influenced our results. It would be useful for future research to manipulate anxiety in a covert manner, so that any experimenter demand is attenuated and the extent to which the current results were, in part, due to experimenter demand could be better understood.

Furthermore, given that emotional states and perceptual-motor calibration (Barrett & Campos, 1987; Carver &

Scheier, 1982; Chow, Ram, Boker, Fujita, & Clore, 2005; Fajen, 2008; Larsen, 2000; Warren, 2006) may change over time, future work would benefit from treating emotions as a continuous factor, either through physiological or self-report measures. In the current study, we grouped individuals into an experimental or control group in order to simplify already complex analyses. It would be beneficial to test the influence of the degree of change in anxiety on perception-action coupling. Previous research has demonstrated performance on cognitive tasks under anxiety induction follow an inverted U-shaped curve, where performance is particularly low when anxiety is both very low or quite high, so it is possible our models averaged over important variability in anxiety responses (Eysenck, 1982). It is unknown whether changes in perceptual-motor calibration for visually guided actions are similarly influenced by differing levels of anxiety. In addition, anxiety rates may have fluctuated within the driving task as participants crashed or stopped close to the stop signs. Future work could test whether possible fluctuations of emotional state due to the performance of the task itself influenced subsequent actions.

Conclusions

In this study, we investigated the influence of anxiety on both a discrete braking and continuous braking task. In the discrete braking task, anxious participants crashed less often, showed a greater sensitivity to crashes on previous trials, and their actions were more sensitively calibrated to visual information. In contrast, anxious participants crashed more often and displayed less stable perceptual-motor calibration in the continuous braking task. The results suggest that anxiety might be best conceptualized as a variable that can alter perceptual-motor calibration and thus performance in a task. The influence of anxiety on performance interacts with the nature of the task and the timescale of the events, which might account for why the influence of anxiety on perception-action is mixed in the literature.

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