Mitigating Bias Blind Spot via a Serious Videogame

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Abstract

We employed a serious video game to train participants on bias blind spot (BBS), capturing training effects on BBS mitigation and knowledge at three points in time. Experiment 1 (N = 703) compared the effects of hybrid training (a combination of implicit and explicit training) to implicit training; Experiment 2 (N = 620) tested the effects of just-in-time versus delayed feedback; and Experiment 3 (N = 626) examined the effects of singleplayer versus multiplayer learning environments. We also tested differences in game duration (30 vs. 60 minute play) and repetition (single vs. repeated play). Overall, the video game decreased BBS linearly over time and increased BBS knowledge at posttest, but knowledge decayed at 8-week posttest. These and other results are discussed, along with the implications, limitations, and future research directions.

Keywords: bias blind spot, mitigation, serious video games, dynamics, time

Mitigating Bias Blind Spot via a Serious Video Game

Video game inductions are prevalent in experimental psychology, neuroscience (Bavelier et al., 2011) and increasingly in education, communication, and the growing field of game studies. Games are a unique and valuable pedagogical tool (Squire & Jenkins, 2004). Scholars have explored video game effects on enjoyment (e.g., Vorderer, Klimmt, & Ritterfeld, 2004), learning (e.g., Gee, 2003; Squire, 2003), violence (e.g., Hartmann, Krakowiak & Tsay-Vogel, 2014; for a review, see Anderson & Bushman, 2001), health (e.g., Peng, 2009), and executive functions (e.g., Buelow, Okdie, & Cooper, 2015). We attempt to make a theoretical contribution to the literature on judgment and decision making by focusing on how video games can be used to mitigate bias, and particularly blind spot (BBS; Pronin, Lin, & Ross, 2002).

BBS is a failure to recognize bias in oneself while overestimating it in others (Pronin et al., 2002). Studies repeatedly demonstrate BBS (e.g., Pronin & Kugler, 2007; Pronin et al., 2002), yet attempts to mitigate this bias (e.g., Frantz, 2006; Lord, Lepper, & Preston, 1984; Pronin et al., 2002; Stapel, Martin, & Schwarz, 1998) have been met with limited success (Pronin, 2007). To mitigate BBS, we developed a serious video game called MACBETH (*Mitigating Analyst Cognitive Bias by Eliminating Task Heuristics*). In three experiments, examining game effects over time, we manipulated game duration, the number of times participants played, the kind of bias-training and feedback they received, and whether players trained alone or with partners to determine which conditions may be more favorable for BBS mitigation and knowledge improvement. We begin our paper with an explanation of what BBS is and why this bias poses a problem for decision making.

Bias Blind Spot

BBS stems from the unconscious tendency to value one's knowledge, experiences, and introspections over the knowledge, experiences, and introspections of others (Pronin & Kugler, 2007). The underlying mechanism responsible for BBS is introspective weighting (Pronin, 2009): Because people have a ready access to their own introspective information, but not to the introspections of others, they tend to overestimate the diagnostic utility of their own introspections (Pronin & Kugler, 2007). For example, when considering our favorite sports team's chances to win in a tournament, we might think our own predictions about our team are more accurate than the predictions of others. After all, we have thought a lot about our team and followed its successes and failures, so in our minds our thoughts about its chances to win are based on a careful analysis. Conversely, when thinking about the reasons why other people would favor a team—because we do not have access to their thoughts—we are quick to dismiss their reasoning as being biased solely due to team loyalty.

BBS is detrimental to human judgment (Frantz, 2006; Pronin & Schmidt, 2013; cf., Gigerenzer & Gaissmaier, 2011), often with serious consequences. For example, corporate executives may ignore the role of self-benefit in their questionable business practices, doctors may be blind to the role of financial self-gain in providing substandard patient care, employers may deny the role of sexism in discriminatory promotions, and politicians may ignore the role of their own ideology in their support of social policies (Pronin & Schmidt, 2013). Clearly, finding successful strategies to mitigate BBS would offer an important step in improving human decision-making processes. In the section below, we discuss the difficulties previous research has encountered attempting to mitigate BBS and present an alternative mitigation approach.

Mitigating BBS. Because people believe they would know if they were biased (Pronin, 2007), forewarning strategies directing them to avoid bias have been marginally effective at best, and reinforcing at worst (Frantz, 2006; Lord et al., 1984; Pronin et al., 2002; Stapel et al., 1998).

As Frantz (2006) noted, "encouraging people to be fair as a means of correcting bias may cause them simply to state more emphatically what they have already concluded. From their perspective, they *are* being fair" (p. 158).

Research on metacognition examining thoughts about one's own cognitive processes (Tormala, Clarkson, & Petty, 2006) may shed light on why forewarning mitigation strategies can be counterproductive. When people are unable to remember examples of their own biased decision making—as a result of introspective weighing—they arrive at a metacognitive conclusion supportive of their initial belief in their own lack of bias. Metacognitive conclusions that support one's own initial beliefs have been shown to increase self-confidence about those beliefs (Tormala et al., 2006). Thus, forewarning mitigation strategies may be ineffective because, instead of causing people to reexamine their conclusions about their own biases, such forewarnings reinforce the certainty with which people hold themselves to be unbiased.

Yet, research on metacognition may offer an effective approach to mitigating BBS. For example, Tormala et al. (2006) made their participants believe they generated weak arguments, causing participants to metacognitively conclude they resisted a persuasive message poorly. As a result, the participants became less certain about their attitudes, and more vulnerable to counter-persuasion. Concerning BBS, these findings suggest exposing people to evidence demonstrating their susceptibility to bias may reduce their certainty about their own lack of bias and make them more receptive to counter-persuasion in the form of bias training.

In our study, a bias-training serious video game served as the delivery system through which evidence of being biased was presented to players. The game offered players opportunities to demonstrate bias, and their biased decisions were revealed to them either implicitly through a reward structure of the game (e.g., through loss of points for biased decisions), or explicitly through bias education. By observing how their biases had cost them points—or even the entire game—players could more easily metacognitively evaluate their own actions in the game as demonstrably biased, thereby sensitizing them to their own BBS. Below, we further discuss how serious video games can be an effective tool for BBS training.

Mitigating BBS via Serious Games

Employing serious games (those for which entertainment is not the main focus; Michael & Chen, 2006) has a longstanding history in education research (Connolly, Boyle, MacArthur, Hainey, & Boyle, 2012). Compared to traditional modes of learning (e.g., lectures), involving intentional acquisition of declarative knowledge, serious video games are learner-centered, interactive, and involving (Garris, Ahlers, & Driskell, 2002), allowing users to internalize information experientially through active engagement with the material by learning through practice (Ciavarro, Dobson, & Goodman, 2008). Games have the ability to "stimulate the imagination, spark curiosity, encourage discussion and debate, and enable experimentation and investigation" (Squire & Jenkins, 2004, p. 9). Indeed, research demonstrates that both problem solving and decision making can be improved through video game play (Buelow et al., 2015).

The opportunity for interactive and experiential learning—a unique feature of video games—is at the core of many educational theories (Kolb, 1984), which posit that players will gain a more in-depth understanding of the subject by solving problems, experimenting with solutions, and becoming aware of the consequences of their actions. Experiential approaches increase awareness of the consequences of a player's actions, thus allowing them to be more aware of their own biases, thereby helping to overcome one of the biggest obstacles to BBS mitigation (Pronin, 2007). Next, we discuss how to incorporate educational training into a videogame.

Implicit vs. Hybrid (Combined Implicit and Explicit) Training in Serious Games

Gaming research indicates implicit learning embedded in games can provide a more enjoyable educational experience as it simulates intrinsic motivation for learning (Ciavarro et al., 2008; Tüzün, Yılmaz-Soylu, Karakuş, İnal, & Kızılkaya, 2009). To make learning more enjoyable, encoding the learning material through game mechanics rather than interrupting the game immersion to explicitly deliver knowledge is advised (Habgood, Ainsworth, & Benford, 2005). However, it is unclear whether this approach always increases learning, since immersive gaming may not be ideal for the acquisition of declarative knowledge (Habgood et al., 2005).

The evidence for the effectiveness of implicit game-based learning comes from research attempting to teach relatively simple content such as geography (Tüzün et al., 2009) or proper sports conduct (Ciavarro et al., 2008). Bias mitigation, in contrast, is more complex as it involves modifying automatic behaviors. High-complexity concepts, such as BBS mitigation, may be better learned by combining explicit and implicit instruction, given that implicit knowledge facilitates easier discovery of the rules and structure of a task, whereas explicit knowledge generates clearer learning models by helping to answer the *why* questions (Mathews et al., 1989).

The research on BBS offers evidence for the effectiveness of an explicit bias training approach. For instance, Pronin and Kugler (2007) conducted a study, in which participants read a short article (ostensibly from *Science*) discussing evidence from classic studies on automatic behaviors and the perils of introspection. The article emphasized the effects of a given bias and the fact that these effects were unconscious. Participants' susceptibility to various biases was then assessed in a purportedly unrelated study. Results indicated the article explicitly educating participants about biases reduced BBS significantly more than the control condition.

In our study, instead of reading an article on BBS, participants received bias education through the video game, wherein bias education was manipulated by either solely incentivizing the unbiased decisions through the reward structure of the game (*implicit-training* condition), or by including an explicit discussion about the biases presented by the game mechanics (*hybrid-training* condition) by pairing the implicit training with explicit instruction. Thus, we predict:

H1: Hybrid (vs. implicit) training (a) increases BBS knowledge and (b) reduces BBS.

Effects of Repeated Play and Game Duration on BBS

Due to challenges associated with modifying automatic behaviors, an opportunity to observe oneself fail, followed by multiple instances of bias mitigation practice, should help players internalize the knowledge they need to improve performance in the future. Consequently, the more participants play the game, the more knowledge they should accumulate about biases, and the more BBS should be mitigated. Similar to repetition, increasing play duration should also improve BBS knowledge and reduce biased judgments. In education research, study duration consistently correlates with increased learning (e.g., Clark & Linn, 2003). This reasoning provides the basis for two further predictions:

H2: Repeated (vs. single) play (a) increases BBS knowledge and (b) reduces BBS.

H3: Longer (vs. shorter) duration (a) increases BBS knowledge and (b) reduces BBS.

Temporal Effects of Video Game Training on BBS

The temporal dynamics (i.e., changes over time) of BBS mitigation strategies have not previously been examined. Measuring mitigation effects at one point in time, typically immediately after training (as most BBS studies do), provides a very limited view of the mitigation processes at work. To understand the effectiveness of BBS training over time, examining the effects at more than two points across the training trajectory is necessary.

Several factors can affect training effectiveness over time. The decay rate, for example, can be exacerbated by the difficulty of the material being learned (Hildebrand & Scheibner-Herzig, 1986). Training retention also depends on how instruction is delivered: Knowledge acquired through implicit priming may be more robust to decay than explicit knowledge (Tunney, 2003). Furthermore, differences in retention may depend on how memory for educational material (and, arguably, learning) is measured (e.g., recognition vs. knowledge application). For instance, Tulving, Schacter, and Stark (1982) showed participants a list of words that contained target words among other non-target words and asked them to (a) indicate whether they recognized the word (a yes/no measure) and (b) complete word fragments associated with target and non target words (e.g., if a target word was *assassin*, the fragment to complete looked like *a_ _a_ _in*).[1] The retention was measured at one-hour and seven-day delay. Results indicated participants' ability to complete word fragments (indicative of the indirect learning from priming) persisted over time, while word recognition declined. Similarly, because two measures of training effectiveness are used in the present study—BBS mitigation and knowledge—different retention trajectories may occur:

RQ: What are the temporal trajectories of BBS (a) knowledge and (b) mitigation?

For a brief summary of the argument presented in the paper and the overview of the three experiments presented below see Table 2.

Experiment 1: Method

Participants

Participants (*N* = 703; age: 18-62, *M* = 22.03, *SD* = 5.34) were college students at two large public universities: one in the Southern U.S. (*n* = 311; hereafter U1) and the other in the West (*n* = 392; hereafter U2).[2] Forty-seven percent of participants were females; 59% were White, 24% Asian, 8% Hispanic, 4% African American, 2% Native American, and 3% did not fit into the provided categories. Seventy-seven percent spoke English as their first language, and all participants had between 1 and 10 years of education since high school (*M* = 3.24, *SD* = 1.86). There was a 73% retention rate between the pretest, initial posttests, and 8-week posttest.

Demographic differences were noted at the two locations. The U1 sample was recruited university wide, and the U2 sample came from the College of Management, resulting in more English as a second language speakers (ESL, 29.3%) at U2 than at U1 (13.9%). Thus, we controlled for location effects in all subsequent analyses.

Design and Procedure

A 2 (repetition: single play vs. repeated play) × 2 (duration: 30 min vs. 60 min) × 2 (training: implicit vs. hybrid) mixed-model design was employed. The within-subjects factor, time of measurement, was captured at pretest, posttest1, and posttest2 (all administered in the lab), and 8-week posttest (administered as an online survey). For the means, standard deviations, and correlations between all variables in each experiment, see Table 1.

Identical experimental scripts and procedures were used at both locations. Participants completed consent forms, were randomly assigned to conditions, then responded to an online *pretest*, followed by the experimental treatment, and an online *posttest1*.[3] At the end of the session, those assigned to the repeated-play condition were scheduled for a second in-lab appointment one week later to complete *posttest2* after playing the game a second time. Eight weeks from the date of their last gameplay, all participants were emailed an online *8-week posttest*. Participants received $20 for each lab session and $30 for the 8-week posttest.

Experimental Materials: MACBETH Video Game

In MACBETH, players assume the role of an intelligence analyst and are given a series of scenarios describing impending terrorist attacks (Appendix A), which they solve by identifying the suspect, the location, and method of attack. Analysts can use different intelligence sources to gather the information and generate hypotheses about the suspects, locations, and methods of each attack.

In addition to BBS, two other biases—confirmation bias (CB) and the fundamental attribution error (FAE)—were addressed in the game. Because BBS can be inferred on the basis of people' unawareness of their susceptibility to a variety of biases (Pronin et al., 2002), the game mechanics associated with the elicitation and mitigation of FAE and CB can be used as a mechanism helping participants realize their susceptibility to bias in general.[4] Below, we briefly describe the CB and FAE game mechanics to illustrate the mitigation strategies used in the game.

CB is the tendency to seek out information confirming one's pre-existing beliefs and hypotheses while overlooking disconfirming information, with a common result being selective exposure and misinterpretation of information (Nickerson, 1998). MACBETH trained how to mitigate CB by providing analysts with implicit or hybrid instructions encouraging them to delay formulating their hypotheses, while seeking disconfirming information useful in disproving their hypotheses and generating more alternative hypotheses.

The FAE involves the tendency to over-rely on personality traits and dispositional information as explanations for others' behaviors while overlooking situational factors, often resulting in erroneous inferences about others' motivations and behaviors (Harvey, Town, & Yarkin, 1981). To learn how to mitigate FAE, players reviewed old case files to make threat assessments based on suspect profiles, wherein situational cues were written to be more diagnostic for the threat assessment (and rewarded with points) to encourage greater attention to situational rather than dispositional cues, thereby helping players mitigate FAE (for details, see Author Citation 2, 2013).

Independent Variables

Implicit vs. hybrid training. In the implicit training condition, players pursued scenarios where making biased decisions cost them points and sometimes loss of a mission, but they were not explicitly trained on biases. In the hybrid training condition, players received the same training as those in the implicit condition, but were also explicitly instructed and tested on biases as part of their gameplay (see Appendix B for screenshot examples of BBS training). Consistent with Pronin and Kugler (2007), BBS training within MACBETH emphasized the general lack of awareness people have about their own biases. Players also completed multiple-choice pop-up quizzes testing their knowledge of bias definitions. Failure on a quiz resulted in the definition being repeated along with a retest.

Repetition. Participants were randomly assigned to either a single-play or repeated-play condition. Repeated players came to the lab a second time, one week following their initial visit.[5]

Duration. Participants were randomly assigned to either 30- or 60-min play. The game displayed a countdown clock and notified players when they had 5 min left. When time expired, players had to submit their final hypothesis, which ended the game, and were then shown a concluding outcome screen indicating mission failure or success based on their performance.

Dependent Variables

BBS knowledge. At each time of measurement, participants received three multiple-choice questions containing a scenario describing BBS with four response options and a possible score ranging between 0 and 3 (one point for each correct bias identification); they had to determine what bias each scenario represented. For example, one BBS scenario was as follows:

> You are getting ready to sign up for courses for next semester. There is a required class you need to take but several professors are teaching it. To come to an objective decision,

> you research each professor online and decide to choose the professor who gives the most A's and has been rated as the nicest. Your friend is also getting ready to sign up for courses but only picks courses he has taken with professors before. You think his decision is subjective because it is only based of his experience, whereas you view your own decision as objective because you researched the experiences of multiple people.

BBS mitigation. A previously validated BBS measure (Pronin et al., 2002) was used, and a pilot study using a student sample drawn from both locations ($N = 276$) was conducted to generate equivalent BBS subscales for each time of measurement (3 items per time period). We examined mean differences across subsets to ensure item difficulty was equivalent along with reliabilities as an indication of item homogeneity (α range: .75 - .86). Based on the pilot, we used nine of the original 19 scenarios (e.g., self-serving bias, halo effect, hostile media effect; Pronin et al., 2002). Because BBS is conceptualized as blindness to all biases, determining participants' susceptibility to a range of biases (not just the biases that were part of our game) has been a standard approach to measuring BBS (Pronin et al., 2002). Below is a question example:

> Psychologists have claimed that some people show a tendency to favorably view others who are attractive and negatively view others who are unattractive. That is, when someone is attractive, they are judged to be happier, more successful and more intelligent; unattractive people are judged less happy, less successful and less intelligent.

Based on Pronin et al. (2002), all questions were written in the same format. They started with "psychologists have claimed that some people show a tendency," followed by a description of a bias and two questions: (1) "To what extent do you believe you show this effect?" and (2) "To what extent do you believe the average student shows this effect?." A 7-point Likert-type scale (1 = *not at all*; 7 = *strongly*) was used. Based on Pronin et al.'s (2002) approach, BBS was measured by subtracting the peers' perceived susceptibility score from the respondent's perceived susceptibility score (higher scores indicated less perceived self-susceptibility to bias; i.e., greater BBS). Other studies have also successfully used the same approach to measuring BBS (e.g., Pronin & Kugler, 2007; Scopelliti et al., 2015). Item reliabilities were acceptable (pretest α = .70, posttest1 α = .72, posttest2 α = .74, and 8-week posttest α = .70.

Experiment 1: Results and Discussion

We modified the within-subjects factor, time, by collapsing posttest1 and posttest2 into a single level labeled *last posttest* to capture the data from participants' posttests after the last time they completed a survey in the lab, which reduced the time periods from four to three (pretest, last posttest, and 8-week posttest). The reason for collapsing was in part to deal with the listwise deletion, a default option in the repeated-measures analyses in SPSS for dealing with missing data. This approach preserved the responses of participants who, by experimental design, came to the lab only once for posttest1 (vs. twice for posttest1 and posttest2), which would otherwise have been listwise deleted because of missing posttest2 data. Creating the last posttest level also allowed us to separate more precisely the effects of time from the effects of repetition.

Hypotheses Tests

To test hypotheses, we conducted two mixed-model ANOVAs (one for knowledge and one for mitigation). We entered time (pretest vs. last posttest vs. 8-week posttest) as a within-subjects factor, and training (implicit vs. hybrid), duration (30 min vs. 60 min), repetition (single vs. repeated play), and location (U1 vs. U2) as between-subjects factors.

BBS knowledge. The following multivariate effects were significant: a main effect of time, Wilks'Λ = .89, $F(2, 466) = 29.91$, $p < .001$, $\eta_p^2 = .11$, a time by repetition interaction, Wilks' Λ = .97, $F(2, 466) = 8.49$, $p < .001$, $\eta_p^2 = .04$, and a time by training interaction, Wilks' Λ

= .97, $F(2, 466) = 7.98$, $p < .001$, $\eta_p^2 = .03$.

The univariate effects revealed a significant main effect of location, $F(1, 467) = 28.28$, $p < .001$, $\eta_p^2 = .06$: Participants learned more about BBS at U1 ($M_{Adj} = 1.40$, $SE = 0.05$) than at U2 ($M_{Adj} = 1.06$, $SE = 0.04$). Thus, location was retained as a factor in all analyses of BBS knowledge. Because the sphericity assumption was met, Mauchly's $W = 1.00$, $\chi^2(2) = 1.28$, $p = .53$, we report the within-subjects results assuming equal variances of group differences.

H1(a), predicting a video game with hybrid (vs. implicit) training increases knowledge of BBS, was supported by a significant main effect of training, $F(2, 467) = 6.92$, $p = .009$, $\eta_p^2 = .01$: Hybrid training ($M = 1.32$; $SD = 0.05$) increased BBS knowledge more than implicit training ($M = 1.14$; $SD = 0.05$). The above main effect was qualified by a significant time by training interaction, $F(2, 934) = 8.22$, $p < .001$, $\eta_p^2 = .02$ (Figure 1), wherein the notable difference emerged at last posttest, when hybrid training ($M = 1.59$, $SD = 1.07$) improved knowledge significantly more, $t(592.70) = 4.34$, $p < .001$, than implicit training ($M = 1.23$, $SD = 0.98$).

H2(a), predicting repeated (vs. single) play increases BBS knowledge, was supported by a significant main effect of repetition, $F(1, 467) = 6.10$, $p = .01$, $\eta_p^2 = .01$: Repeated play ($M_{Adj} = 1.31$, $SE = 0.05$) increased BBS knowledge more than single play ($M_{Adj} = 1.15$, $SE = 0.05$). Similarly, a significant time by repetition interaction, $F(2, 934) = 8.86$, $p = .001$, $\eta_p^2 = .02$ (Figure 2), indicated repeated play increased knowledge more than single play both at last posttest (repeated play $M = 1.59$, $SD = 1.05$ vs. single play $M = 1.29$, $SD = 1.02$; $t[595] = -3.55$, $p < .001$) and at 8 weeks (repeated play $M = 1.29$, $SD = 1.02$ vs. single play $M = 1.02$, $SD = 0.81$; $t[472.26] = -3.18$, $p = .002$).

H3(a), predicting longer (vs. shorter) gameplay duration increases BBS knowledge, was not supported. Although the time by duration linear contrast was significant, $F(1, 467) = 3.82$, p

= .05, η_p^2 = .01 (Figure 3), we found no significant between-subjects effects.[6] The significant within-subjects effects are discussed as part of RQ(a) below.

RQ(a), concerning the effects of time on BBS knowledge, was answered with several significant interactions and a main effect of time. A significant quadratic contrast of time on BBS knowledge, $F(1, 467) = 57.77$, $p < .001$, $\eta_p^2 = .11$, indicated, regardless of experimental condition, BBS knowledge initially increased from pretest (M = 1.04, SD = 0.99) to last posttest (M = 1.45, SD = 1.04) but then decayed to pretest levels at 8 weeks (M = 1.16, SD = 0.93).

Further, the time by training interaction associated with H1(a) revealed, at last posttest, both types of training improved BBS knowledge (implicit training pretest M = 1.10, SD = 0.98, vs. last posttest M = 1.23, SD= 0.98, t[274] = -3.23, p = .001; hybrid training pretest M = 1.04, SD = 0.98, vs. last posttest M = 1.59, SD= 1.07, t[321] = -7.87, $p < .001$). However, while hybrid training showed improvement from pretest to 8-week posttest, $t_{\text{hybrid}}(247) = -2.11$, p = .04, the effect of implicit training remained the same, $t_{\text{implicit}}(236) = -1.09$, p = .28.

Significant temporal effects also emerged in the time by repetition interaction (Figure 2) associated with H2(a). Single play initially improved BBS knowledge from pretest (M = 1.04, SD = 0.96) to last posttest (M = 1.29, SD = 1.02), $t(318) = -3.69$, $p < .001$, but knowledge decayed to pretest levels at 8 weeks (M = 1.02, SD = 0.81).[7] Repeated play also significantly improved BBS knowledge from pretest (M = 1.01, SD = 1.00) to last posttest (M = 1.59, SD = 1.05), $t(277) = -7.90$, $p < .001$. However, although at 8 weeks (M = 1.29, SD = 1.02) a decay in knowledge had occurred, the BBS knowledge at 8 weeks was still significantly higher than at pretest, $t(251) = -4.15$, $p < .001$.

Finally, we examined the dynamics based on the time by duration linear contrast (Figure 3) associated with H3(a). Both 30-min (pretest M = 1.07, SD = .99 vs. last posttest M = 1.42, SD

= 1.05; *t*[258] = -4.56, $p < .001$) and 60-min play (pretest *M* = 1.00, *SD* = 0.97 vs. last posttest *M* = 1.42, *SD* =1.04; *t*[337] = -6.77, $p < .001$) significantly improved BBS knowledge at last posttest. At 8-weeks posttest, the 30-min play (*M* = 1.09, *SD* = 0.92) decayed to pretest levels, *t*(211) = -0.12, *p* = .91, but 60-min play (*M* = 1.21, *SD* = 0.94), although still resulting in some decay, improved BBS knowledge significantly more, *t*(272) = -3.00, *p* = .003, relative to pretest.

Taken together, the examination of RQ(a) revealed that, despite the overall quadratic effect of time on BBS knowledge (i.e., initial improvement at last posttest and a subsequent decay at 8 weeks), the effects of training, repetition, and to some extent duration, were able to offset the decay in knowledge at 8-week posttest. Specifically, at 8 weeks, hybrid training, repeated play, and 60-min game, although still resulting in some decay relative to the last posttest, significantly improved BBS knowledge relative to the pretest.

BBS mitigation. Multivariate results revealed a significant main effect of time, Wilks'Λ= .91, $F(2, 481) = 25.36$, $p < .001$, $\eta_p^2 = .10$; and significant time by repetition, Wilks'Λ= .98, $F(2, 481) = 5.27$, $p = .005$, $\eta_p^2 = .02$, and time by training by location interactions, Wilks'Λ= .99, $F(2, 481) = 3.78$, $p = .02$, $\eta_p^2 = .02$. Because the sphericity assumption was violated, Mauchly's W = .98, $\chi^2(2) = 10.40$, $p = .006$, all within-subjects effects are reported with Huynh-Feldt correction.[8]

H1(b), predicting that hybrid (vs. implicit) training reduces BBS, was not supported. Although there was a significant three-way time by training by location interaction, $F(2.00, 964.00) = 3.50$, $p = .03$, $\eta_p^2 = .01$, no between-subjects differences were significant. The significant within-subjects effects are discussed as part of RQ(b) below.

H2(b), predicting that repeated (vs. single) play reduces BBS, was partially supported by the significant time by repetition interaction, $F(2.00, 964.00) = 4.93$, $p = .007$, $\eta_p^2 = .01$. The notable difference between repeated and single play (see Figure 4), emerged at last posttest, when repeated play ($M = 1.45$, $SD = 2.81$) reduced BBS significantly more, $t(593.73) = 3.33$, $p < .001$, than single play ($M = 2.25$, $SD = 3.06$).

Gameplay duration did not significantly affect BBS, thus H3(b) was not supported.

RQ(b) concerning temporal trajectories of BBS mitigation was answered with a main effect and an interaction. A significant linear contrast of time, $F(1, 482) = 45.44$, $p < .001$, $\eta_p^2 = .09$, indicated, regardless of experimental condition, playing MACBETH significantly, $t(597) = 5.85$, $p < .001$, reduced BBS from pretest ($M = 2.76$, $SD = 3.21$) to last posttest ($M = 1.84$, $SD = 2.92$), and this reduction in bias remained the same at 8-week posttest ($M = 1.63$, $SD = 2.61$; $t[497] = 1.43$, $p = .15$).

Additional temporal effects emerged based on the aforementioned significant three-way time by training by location interaction associated with H1(b). Paired-sample *t* tests indicated BBS reduction at both locations for both hybrid ($t_{U1}[139] = 4.94$, $p < .001$; $t_{U2}[182] = 2.19$, $p = .03$) and implicit training ($t_{U1}[125] = 2.13$, $p = .04$; $t_{U2}[148] = 2.44$, $p = .02$) from pretest to last posttest. At 8-week posttest, the effect of hybrid training remained the same at both locations, and only the effect of implicit training significantly reduced BBS at U1 ($t_{U1}[108] = 2.36$, $p = .02$) Overall, from pretest to 8-week posttest, temporal trajectories indicated that both hybrid ($t_{U1}[116] = 4.60$, $p < .001$; $t_{U2}[140] = 2.96$, $p = .004$) and implicit training ($t_{U1}[109] = 3.39$, $p = .001$; $t_{U2}[132] = 2.79$, $p = .006$) significantly reduced BBS.

In sum, Experiment 1 results suggest a serious video game can be effective for bias training. We found a significant increase in BBS knowledge from pretest to last posttest and a significant decrease in BBS from pretest to 8-week posttest. It appears MACBETH's effect on knowledge was more susceptible to decay than its effect on mitigation, which remained at the same reduced level of BBS after 8 weeks. Our results also revealed repeated play improved both BBS knowledge and mitigation at last posttest and 8 weeks. Furthermore, a hybrid approach pairing implicit training with explicit instruction was more effective than implicit training alone at increasing knowledge (but not mitigation). The initial success of hybrid training, however, appears to decay at 8 weeks. Based on these results, hybrid training was used in Experiment 2 to further test the effects of duration and repetition in a modified version of MACBETH incorporating bias-training feedback.

Experiment 2: Feedback

Because of the complexity of bias mitigation, providing learners with constructive feedback may be critical for improvement in BBS knowledge and mitigation. Gaming research indicates early and detailed feedback affects player performance (Delacruz, 2012), helping to guide and improve acquisition of knowledge (Moreno, 2004). Feedback is particularly important for novice players who tend to become overwhelmed with the complexity of game mechanics, and thus become distracted from training (Serge, Priest, Durlach, & Johnson, 2013). Feedback is most effective when it helps players understand learning objectives by providing clear criteria on how to succeed and how to assess goal achievement (Hattie & Timperley, 2007). However, feedback designed to guide players through their successes and errors has been associated with increased learning only when paired with feedback providing players with scores, grades, and other accomplishment metrics (Shute, 2008).

There is also a downside to feedback. It may slow down the immersive experience and may be perceived by players as a barrier to their game performance, especially if time constraints are involved (Ryan & Pintrich, 1997). As a result, players often avoid seeking feedback on their own (Nelson, 2007). Thus, providing feedback represents a balance between ensuring learning and avoiding interruptions to the game flow. Such disruptions may be remedied by delaying feedback until a meaningful segment of the game is completed, when a performance review can be offered without detracting from the game flow. Although this approach may preserve game flow, delayed feedback will no longer be immediately tied to a specific player action, thus it may be relatively less beneficial to learning (Delacruz, 2012).

Experiment 2 tested the effectiveness of immediate feedback (referred to as *just-in-time feedback* or *JIT*) on players' bias training performance compared to *delayed feedback* delivered at the end of a scenario. Based on the above reasoning regarding the effectiveness of immediate feedback on learning (and in spite of its potential to disrupt game flow), we predict:

H4: JIT (vs. delayed) feedback (a) increases BBS knowledge and (b) reduces BBS.

In addition, Experiment 2 further tested the effects of duration, repetition, and time.

Experiment 2: Method

Participants

Participants (N = 620; age: 18-55, M = 21.35, SD = 4.95) were college students from the same two universities (U1 n = 291; U2 n = 329) as in Experiment 1. Participants were 58% females; 57% were white, 17% Asian, 13% Hispanic, 4% African American, 4% Native American, and 4% did not fit into the provided categories. Eighty percent spoke English as their first language. All participants had between 1 and 10 years of education since high school (M = 2.77, SD = 1.98). There was a 19.7% attrition rate between pretest and 8-week posttest. The data from 2% of participants were removed from analyses due to either not finishing the survey, receiving the wrong survey in the lab, or stopping play before time expired.

Design and Procedure

The experimental procedures were identical to Experiment 1 with one exception: All participants were prescreened for knowledge of English, testing vocabulary from the game. A participant who failed a test was not invited to participate in the experiment. A 2 (repetition: single play vs. repeated play) × 2 (duration: 30 min vs. 60 min) × 2 (feedback: JIT vs. delayed) mixed-model design was used, with time as a within-subjects factor. As mentioned, we retained hybrid-training version of MACBETH, which was modified to include feedback.

Independent Variables

Feedback. Participants received both feedback about biases to facilitate unbiased decision making and outcome feedback in the form of in-game performance scores (see Appendix C for screenshot examples). Feedback came from different mentors, both in text and audio. In the JIT condition, feedback was given immediately after performing an action related to either elicitation or mitigation of bias. BBS feedback was carefully formulated to avoid triggering defensiveness (Franz, 2006; e.g., "You're doing well but remember to be mindful. We all have a bias blind spot to look out for"). In the delayed-feedback condition, a mentor provided the identical feedback, but at the end of the scenario, presented one item at a time, arranged by game turns.

Repetition and duration. We used the same manipulations as in Experiment 1.

Dependent Variables: BBS Measures

The same BBS knowledge and mitigation measures were used as in Experiment 1. The BBS mitigation reliabilities were likewise acceptable (pretest $\alpha = .62$, posttest1 $\alpha = .72$, posttest2 $\alpha = .75$, and 8-week posttest $\alpha = .75$).

Experiment 2: Results and Discussion

The same two mixed-model ANOVAs as in Experiment 1 were conducted, but instead of training, we entered feedback (JIT vs. delayed) as one of the between-subjects factors.

BBS knowledge. Two multivariate effects were significant: a main effect of time, Wilks' Λ= .79, $F(2, 358) = 46.89$, $p < .001$, $\eta_p^2 = .21$, and a four-way time by repetition by feedback by location interaction, Wilks'Λ= .97, $F(2, 358) = 5.32$, $p = .005$, $\eta_p^2 = .03$. The significant main effect of location, $F(1, 359) = 5.88$, $p = .02$, $\eta_p^2 = .02$, indicated BBS knowledge improved more at U1 ($M_{Adj} = 1.33$, $SE = 0.05$) than at U2 ($M_{Adj} = 1.16$, $SE = 0.05$); thus, we kept location as a factor in the analyses of BBS knowledge. The sphericity assumption was not met, Mauchly's $W = .96$, $\chi^2(2) = 14.00$, $p = .001$: We report within-subjects effects with Huynh-Feldt correction.[9]

H2(a), predicting repeated (vs. single) play increases BBS knowledge, was supported by a significant main effect of repetition, $F(1, 359) = 8.30$, $p = .004$, $\eta_p^2 = .02$: Overall, repeated play ($M_{Adj.} = 1.35$, $SE = 0.05$) increased knowledge more than single play ($M_{Adj} = 1.14$, $SE = 0.05$).

Repetition was also involved in a significant four-way time by repetition by feedback by location interaction, $F(2.00, 718.00) = 4.69$, $p = .009$, $\eta_p^2 = .01$. Because none of the between-subjects effects were consistent with the hypothesized relationships, H3(a) concerning the effects of duration and H4(a) concerning the effects of feedback were not supported. The significant within-subjects effects of this interaction are discussed as part of RQ(a) below.

RQ(a) was answered by a significant main effect and an interaction. A significant quadratic contrast for time on BBS knowledge, $F(1, 359) = 93.88$, $p < .001$, $\eta_p^2 = .21$, indicated, regardless of experimental condition, BBS knowledge had initially increased from pretest ($M = 1.04$, $SD = 0.97$) to last posttest ($M = 1.58$, $SD = 1.02$) but then reduced to almost pretest levels ($M = 1.11$, $SD = 0.93$) at 8 weeks.

The aforementioned time by repetition by feedback by location interaction associated with H3(a) and H4(a) indicated a significant improvement in BBS knowledge from pretest to last posttest within certain conditions. At both locations, an increase in knowledge occurred when delayed feedback was paired with repeated play (U1: $t[47] = -3.57$, $p = .001$; U2: $t[47] = -4.04$, $p < .001$). When JIT feedback was paired with single play, significant improvement in knowledge was also found, but only at U1, $t(50) = -3.88$, $p < .001$. At 8 weeks, BBS knowledge decayed in all conditions that were part of this interaction.

BBS mitigation. Because neither multivariate nor univariate effects of location were significant, location was removed from the mitigation analyses, and the model was reanalyzed. The following multivariate effects were significant: a main effect of time, Wilks'Λ= .91, $F(2, 398) = 19.51$, $p < .001$, $\eta_p^2 = .09$, and a time by repetition interaction, Wilks'Λ= .97, $F(2, 398) = 5.31$, $p = .005$, $\eta_p^2 = .03$. The assumption of sphericity was met, Mauchly's $W = .99$, $\chi^2(2) = 3.63$, $p = .16$: We report within-subjects effects assuming equal variances of group differences.

H2(b), predicting that repeated (vs. single) play of the video game reduces BBS, was not supported, despite a significant time by repetition interaction, $F(2, 798) = 5.12$, $p = .006$, $\eta_p^2 = .01$ (Figure 5). In the interaction, the only significant difference in repetition was not in the predicted direction: At last posttest, contrary to H2(b), single play ($M = 1.34$, $SD = 2.68$) reduced BBS significantly more, $t(355.25) = -3.15$, $p = .002$, than repeated play ($M = 2.24$, $SD = 3.46$).[10] The significant within-subjects effects of the interaction are discussed as part of RQ(b) below.

Further, due to nonsignificant results, H3(b) concerning the effects of duration and H4(b) concerning the effects of feedback were also not supported.[11]

RQ(b) was answered by a significant main effect and an interaction. A significant linear contrast of time, $F(1, 399) = 37.61$, $p < .001$, $\eta_p^2 = .09$, indicated, regardless of experimental condition, BBS reduced linearly over time (pretest $M = 2.64$, $SD = 3.00$ vs. last posttest $M = 1.81$, $SD = 3.07$ vs. 8-week posttest $M = 1.67$, $SD = 2.79$). Additional temporal effects emerged as part of the aforementioned significant time by repetition interaction (Figure 5) associated with H2(b). Although at last posttest single play significantly decreased BBS (pretest $M = 2.40$, $SD = 2.82$ vs. last posttest $M = 1.34$, $SD = 2.70$; $t[311] = 5.21$, $p < .001$), at 8 weeks its effect ($M = 1.83$, $SD = 2.74$) remained the same, $t(237) = -1.61$, $p = .11$. Repeated play reduced BBS linearly and significantly from pretest ($M = 2.81$, $SD = 3.09$) to last posttest ($M = 2.23$, $SD = 3.48$), $t(201) = 2.54$, $p = .01$, and from last posttest ($M = 2.29$, $SD = 3.24$) to 8-week posttest ($M = 1.47$, $SD = 2.81$), $t(174) = 3.57$, $p < .001$, where it caught up with the effects of the single play.

In sum, feedback did not make a discernable difference for BBS training in Experiment 2. Similarly, we did not find support for the effects of duration on either BBS mitigation or knowledge. However, as in Experiment 1, repeated play increased knowledge more than single play. The effects of repetition on mitigation only emerged over time: Repeated play significantly reduced BBS from pretest to last posttest and from last posttest to 8 weeks. However, at last posttest, single play reduced BBS more than repeated play, and only at 8 weeks the effects of repeated play became comparable to single play. Overall, regardless of experimental condition, playing MACBETH reduced BBS linearly over time and improved BBS knowledge at last posttest, but the improvement in knowledge decayed at 8 weeks.

Since bias training is complex, we felt players would learn more from immediate feedback. Thus, in Experiment 3, we retained JIT feedback, which we improved in the hopes of maintaining game flow: The corrective feedback about bias-related errors was edited to be more concise, the amount of positive feedback was reduced by shortening its length, and the vocal delivery was sped up to minimize the interruption of game flow.

In Experiment 3, we examined the effects of learning environment, operationalized as training in the single-player versus multiplayer game. There is evidence indicating collaborative environments may be beneficial for mitigating such biases as CB (Tschan et al., 2009), but whether they are likewise effective for BBS mitigation remains to be seen. Thus, in addition to testing the effects of repetition and duration, comparing the effects of a single-player to a multiplayer game on BBS mitigation and knowledge were the foci of Experiment 3.

Experiment 3: Learning Environment

Multiplayer games are gaining popularity (Taylor, 2006). In these types of games, players can communicate to solve problems and collaboratively achieve individual and group goals (Dickey, 2011). Collaborative virtual environments may be used successfully to improve the acquisition of abstract concepts (Michael & Chen, 2006). Although the evidence for the effects of multiplayer learning environments on bias mitigation is scant, the findings of the small group research suggests that collaborative environments may be effective in reducing bias in decision making. One study, examining the effect of doctor communication on diagnostic accuracy, found doctors who talked through their reasoning in front of a group of other doctors made better diagnoses because talking to people with different opinions provided an opportunity for disconfirming feedback (Tschan et al., 2009). Thus, when people make decisions and have to explain their reasoning in front of others, they might be less prone to CB.

Whether the mitigation approach involving decision justification to other people or the opportunity for feedback from others is effective for BBS mitigation has to be investigated. Because BBS arises in part as an ego defense and self-enhancement (Pronin, 2007), having to reveal your own biases to others may trigger defensiveness and denials of being biased instead of mitigation. When it comes to BBS, social comparison activates the exact processes that we are trying to combat—over-relying on ones' own introspective information. Therefore, BBS may be better mitigated in a single-player game. Based on this reasoning, we predict:

H5: Single-player (vs. multiplayer) learning environment (a) increases BBS knowledge and (b) reduces BBS.

In addition, in Experiment 3, we further examined the repetition (H2) and duration (H3) effects on BBS mitigation and knowledge along with their temporal dynamics (RQ).

Experiment 3: Method

Participants

Participants ($N = 626$; age: 18-61, $M = 21.63$, $SD = 4.09$) were college students from the same two universities as in prior Experiments (U1: $n = 309$; U2: $n = 317$). Participants were 49% females; 68% were white, 12% Asian, 10% Hispanic, 5% African American, 2% Native American, and 2% did not fit into the provided categories. Eighty-six percent spoke English as their first language. All participants had between 1 and 10 years of education since high school ($M = 3.19$, $SD = 1.82$). There was a 33% attrition rate between pretest and 8-week posttest. The data from 1% of participants were removed from analyses due to either not finishing the survey, receiving the wrong survey in the lab, or stopping play before time expired.

Design and Procedure

The procedures were identical to Experiment 2. A 2 (repetition: single play vs. repeated play) × 2 (duration: 30 min vs. 60 min) × 2 (learning environment: single-player vs. multiplayer) mixed-model design was employed with time entered as a within-subjects factor. The game with hybrid training and JIT feedback was modified into either a single-player or multiplayer version.

Independent Variables

Learning environment (single-player vs. multiplayer). Participants in the multiplayer condition played either with another human participant ($n = 71$) or, when another participant was not available, with artificial intelligence (AI; $n = 114$), or partly with both (with another participant and, when he/she quit, with the AI; $n = 149$). Following past research demonstrating differences between human and computer players (Weibel, Wissmath, Habegger, Steiner, & Groner, 2008), differences between those who played with a human versus the AI were tested but were not significant. Participants also reported they did not see the difference between playing with the AI versus a human player and were not aware when their partner was replaced by the AI. Thus, the data from participants who played with an AI were included into the multiplayer condition.

The multiplayer game (see Appendix D for screenshot examples) differed from a single-player version in several ways. The single-player game allowed for very limited interactivity: Players could view the hypothesis of other AIs (in-game agents) and request confirming or disconfirming intelligence from them on even turns; they then received feedback based on the kind of evidence they chose. In the multiplayer game, players had to make decisions and formulate hypotheses collaboratively. They could also request help from another analyst (their partner in the game) on even turns. In return, the player's partner had to provide intelligence and could earn points by offering justification for hypotheses based on evidence. The intelligence from the partner would then appear in the player's dropbox. Partners would receive feedback about the information they supplied. The same sequence of events occurred when players requested information from their partners.

Another difference pertained to how the final hypothesis for the game was submitted. In the single-player game, after a final hypothesis was submitted, points were assigned for correct portions of the hypothesis. A hypothesis without sufficient supporting evidence received a penalty. In the multiplayer game, the player's partner had to approve a final hypothesis. A partner could reject a hypothesis by submitting disconfirming intelligence to the player's dropbox; the rejecting partner then received points, and the player received a penalty. If a partner approved a hypothesis, the player received a bonus. Both partners shared the final approved hypothesis and received points for correct items.

Repetition and duration. We used the same manipulations as in Experiments 1 and 2.

Dependent Variables: BBS Measures

We used the same BBS knowledge measures as in prior Experiments, but the mitigation measures were modified. First, we made the BBS mitigation questions more applicable to participants in our study by rewording the second BBS question, so that the question asked about *others with similar levels of training to yourself* exhibiting the effect, instead of the *average student*. We expected this change should increase the sensitivity of this measure (Pronin et al., 2002). Second, 20 additional questions not available prior to Experiment 3 were added by adapting items from other research teams funded by the same funding agency (Martey et al., 2014; Scopelliti et al., 2015; Stromer-Galley et al., 2013). These changes improved item reliabilities relative to prior Experiments (pretest $\alpha = .85$, posttest1 $\alpha = .87$, posttest2 $\alpha = .89$, and 8-week posttest $\alpha = .90$).

Experiment 3: Results and Discussion

Because interdependence in the multiplayer condition violates the assumption of independent observation required for the analyses based on the general linear model such as ANOVA and *t* test, a series of intraclass correlations were conducted to ascertain the degree of interdependence between participant-participant dyads (Kenny, Kashy, & Cook, 2006). None of these intraclass correlations between a given participant's posttest BBS scores and his/her game partner's posttest BBS scores were significant, indicating a lack of interdependence in the data.

Hypotheses Tests

Here as well, two mixed-model ANOVAs were conducted, but instead of feedback, we entered learning environment (single-player vs. multiplayer) as a between-subjects factor.

BBS knowledge. The following multivariate effects were significant: a main effect of time, Wilks'Λ= .94, $F(2, 309) = 10.04$, $p < .001$, $\eta_p^2 = .06$, a time by repetition interaction, Wilks'Λ= .98, $F(2, 309) = 3.43$, $p = .03$, $\eta_p^2 = .02$, a time by location interaction, Wilks'Λ= .98, $F(2, 309) = 2.95$, $p = .05$, $\eta_p^2 = .02$, and a time by learning environment by duration interaction, Wilks'Λ= .97, $F(2, 309) = 5.65$, $p = .004$, $\eta_p^2 = .04$.

A significant main effect of location, $F(1, 310) = 10.99$, $p = .001$, $\eta_p^2 = .03$, indicated, overall, more BBS knowledge was acquired at U1 ($M_{Adj} = 1.81$, $SE = 0.06$) than at U2 ($M_{Adj} = 1.51$, $SE = 0.07$); thus, we kept location as a factor in the analyses of BBS knowledge. Because the sphericity assumption was met, Mauchly's $W = .99$, $\chi^2(2) = 4.45$, $p = .11$, we report the within-subjects results assuming equal variances of group differences.

H2(a), predicting repeated (vs. single) play increases BBS knowledge, was supported by a significant main effect of repetition, $F(1, 310) = 7.16$, $p = .008$, $\eta_p^2 = .02$: Repeated play ($M_{Adj.} = 1.78$, $SE = 0.06$) increased BBS knowledge more than single play ($M_{Adj} = 1.53$, $SE = 0.07$). However, this effect was qualified by a significant time by repetition interaction, $F(2, 620) = 3.07$, $p = .05$, $\eta_p^2 = .01$ (Figure 6): Over time a significant difference emerged only at last posttest where repeated play ($M = 2.00$, $SD = 0.97$) increased BBS knowledge more, $t(394.24) = -5.14$, $p < .001$, than single play ($M = 1.53$, $SD = 1.00$).

Despite the significant duration by learning environment interaction, $F(1, 310) = 5.21$, p

= .02, η_p^2 = .02, and time by learning environment by duration interaction, $F(2, 620) = 6.15$, p = .002, η_p^2 = .02, H3(a) concerning the effects of duration and H5(a) concerning the effects of learning environment on BBS knowledge were not supported: None of the between-subjects comparisons revealed effects consistent with the hypothesized relationships. (Similarly, the within-subjects effects revealed no significant improvement in knowledge.)

The examination of RQ(a) concerning temporal effects on BBS knowledge, revealed a significant quadratic contrast of time, $F(1, 310) = 14.01$, $p < .001$, $\eta_p^2 = .04$: Regardless of experimental condition, BBS knowledge increased from pretest (M = 1.69, SD = 1.03) to last posttest (M = 1.79, SD = 1.02) but then decayed at 8-week posttest (M = 1.43, SD = 1.01).

Temporal trajectories from the aforementioned significant time by repetition interaction (Figure 6) associated with H2(a) revealed single play resulted in a gradual decrease in BBS knowledge from pretest to last posttest and then from last posttest to 8-week posttest; and although each separate decrease in knowledge was not significant, the decrease from pretest to 8-week posttest was significant, $t(188) = 3.17$, $p = .002$. Conversely, repeated play significantly increased BBS knowledge from pretest to last posttest, $t(184) = -4.57$, $p < .001$, but BBS knowledge decayed significantly at 8 weeks, $t(136) = 5.38$, $p < .001$.

BBS mitigation. Because neither multivariate nor univariate effects of location were significant, location was removed from the mitigation analyses, and the model was reanalyzed. The multivariate results revealed a significant main effect of time, Wilks'Λ= .92, $F(2, 317)$ = 13.15, $p < .001$, $\eta_p^2 = .08$. No other multivariate or between-subjects effects were significant. Thus, H2(b) concerning the effects of repetition, H3(b) concerning the effects of duration, and H5(b) concerning the effects of learning environment on BBS were not supported.

RQ(b) was answered with a significant linear contrast of time, $F(1, 318) = 26.01$, p <

.001, $\eta_p^2 = .08$, indicating, regardless of condition, MACBETH reduced BBS linearly over time (pretest $M = 6.16$, $SD = 6.07$; last posttest $M = 4.57$, $SD = 6.25$; 8 weeks $M = 3.67$, $SD = 6.08$).

In sum, the differences in learning environment did not apparently affect BBS mitigation and knowledge. However, similar to the effects of prior Experiments, regardless of condition, MACBETH either reduced BBS linearly over time, or initially improved BBS knowledge, which then decayed after 8 weeks. Similar to Experiment 2, no support was found for the duration effects on either BBS mitigation or knowledge. Although repetition did not affect mitigation, it did affect knowledge: Overall, repeated play led to greater BBS knowledge than single play. However, the temporal trajectories for repetition indicated repeated play increased BBS knowledge only at last posttest, and knowledge then decayed at 8-week posttest.

General Discussion

Serious games have been previously used as an effective learning tool to teach simple educational concepts (e.g., Ciavarro et al., 2008; Tüzün et al., 2009), but they have also shown promise for more complex cognitive functions like decision making and problem solving (e.g., Buelow et al., 2015). Our results indicate serious games can be applied successfully to the mitigation of cognitive biases. To date, very few published studies have attempted to apply serious video game training to the mitigation of any cognitive biases (but see Author Citation 1, 2014), much less BBS. Changing well-practiced and automatic behaviors poses a challenge, and these results suggest using serious video games for bias mitigation offers one promising avenue.

In three experiments (for a comparison of representative results across experiments, see Table 3), we examined the effects of different video game features (training, feedback, and learning environment) along with the effects of repeated play and duration on their ability to mitigate BBS. In Experiment 1, hybrid training increased BBS knowledge more than implicit training, but training did not affect mitigation. These results suggest some initial success of hybrid training, which should be investigated further in future research.

In Experiment 2, feedback was introduced into the game to enhance the effectiveness of hybrid training. Both types of feedback were expected to have limitations: We thought JIT would increase learning at the cost of game engagement and delayed feedback would offer better game flow, but also less effective learning. However, feedback did not appear to affect BBS mitigation and knowledge. These feedback results may have been a function of the limitations of each type of feedback cancelling out its own advantages. Perhaps interruptions to game flow to deliver JIT feedback were still tolerable when playing MACBETH once, but during repeated play the continued interruptions of JIT feedback were likely too disruptive, which may be why the delayed feedback was more effective when the game was played repeatedly (the temporal effects and participants qualitative responses to some extent support this conclusion). Future serious games designed to mitigate bias should strive for an optimal balance between game experience or flow and educational content to more effectively facilitate learning of complex information.

Based on expectations of less defensiveness and reliance on introspection within a single-player relative to a multiplayer game, Experiment 3 examined the effects of learning environment on BBS mitigation and knowledge. We did not find significant differences in learning environment. These null results were perhaps due to the conceptualization of multiplayer versus single-player versions within MACBETH: Neither version was particularly threatening to participants' egos, possibly obviating one of the causes of an increase in BBS. However, based on improvements in BBS mitigation and knowledge over time—regardless of experimental condition—our results seem to indicate that both single-player and multiplayer versions are capable of facilitating positive outcomes.

The effects of repetition and duration were examined across the three experiments. The effects of duration produced null results (except for a significant improvement in BBS knowledge from pretest to 8-week posttest as a result of the 60-min game in Experiment 1), which may have been due to a lack of significant qualitative differences between the 30-min and 60-min versions of MACBETH. Simply put, 30-min and 60-min plays were not sufficiently different. Since the game was challenging and involved a learning curve, perhaps examining 60 min versus 120 min or 240 min would have yielded greater differences as a result of duration.

The decision to create a challenging video game was intended to facilitate greater replayability. It stands to reason that greater game engagement should result in greater improvement in BBS mitigation and knowledge. Indeed, the effect of replayability (i.e., repetition) on BBS knowledge, although not mitigation (except for Experiment 1), was consistently demonstrated across the three experiments, wherein repeated play resulted in greater knowledge than single play. In sum, greater learning is likely a result of longer and more frequent gameplay.

Unlike any published study on BBS to our knowledge, we examined the temporal trajectories associated with BBS mitigation and knowledge. The dynamics of BBS training across all experiments indicate MACBETH consistently improved BBS knowledge at last posttest, but its effects decayed at 8 weeks. On the other hand, the effects of mitigation improved linearly over time. Such different retention rates are not surprising considering the differences in how mitigation and knowledge were captured. Knowledge measures reflected participants' familiarity with biases and their ability to differentiate between them. To make video game engaging, a substantially smaller portion of the gameplay was dedicated to familiarization. The specific mitigation strategies relevant to each bias presented in the game were introduced implicitly and were arguably more fun to learn and practice, since this portion of the training was tied directly to the reward structure in the game and players' ability to solve the mystery, successfully complete scenarios, and win the game.

Our findings regarding training retention rates and particularly the decay in knowledge at 8-week posttest are consistent with the aforementioned research on implicit and explicit training (e.g., Tunney, 2003). However, the fact that mitigation effects did not decay after 8 weeks is somewhat surprising. Participants only played this technical and complex game for a relatively short period of time—no more than 120 min in the repeated-play condition. The 8-week delay was unusually long compared to most attitude change studies, where temporal trajectories tend to be measured in intervals ranging from a few minutes to a few weeks at the most (e.g., Banas & Rains, 2010; Kaplowitz, Fink, & Bauer, 1983). Still, MACBETH not only mitigated BBS but produced lasting effects under certain conditions. Finding improvement in BBS after 8-week delay can be explained in part on the basis of findings from attitude dynamics research, indicating attitude change can occur even in the absence of new information (e.g., Tesser, 1978), or additional training. Perhaps, for BBS mitigation, some period of delay is desirable if not essential for allowing the effects of mitigation training to germinate. This idea should be investigated further in future research.

This study has a few limitations that merit discussion. First, some of the effect sizes are relatively small. However, small effect sizes are meaningful in research on phenomena that are resistant to change (Pfau, Haigh, Sims, & Wigley, 2007), such as the mitigation of bias. Given that this study is one of the first of its kind, small effects should not be discounted. Second, although we showed that serious games can be effective for BBS training, conclusions about the mechanisms that reduced BBS require further research to empirically demonstrate the processes responsible for training effectiveness. Finally, MACBETH is a specific genre of video games dealing with a specific context (intelligence gathering and terrorism). Additional replications with other training video games would help establish the generalizability of these results.

In conclusion, this study presents one attempt at BBS training and mitigation in a serious video game. Serious games have been found to successfully reduce other types of bias (Author Citation 1, 2014), but BBS remains a more difficult challenge. Our results present an important initial effort at using this promising new approach, demonstrating mitigation success over time. We found increased repetition, hybrid training, and mere engagement with the video game can improve knowledge and in some cases mitigation of bias. Future investigations could profitably examine what hinders the decay of training effects and what degree of repetition is optimal. These findings offer theoretical and practical implications for researchers and practitioners interested in pursuing a range of future research directions through the use of serious games.

References

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Author Citation 2. (2013). Citation details removed for blind review.

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Footnotes

[1]All words were low frequency seven-letter words, and a total pool of 192 words was used, making retention task challenging.

[2]Participants who completed Experiment 1 were precluded from participating in Experiment 2 or 3. Similarly, Experiment 2 participants could not complete Experiment 3.

[3]Random assignment was done in blocks of 20 people based on gameplay duration to avoid participants in different duration (30- vs. 60-min) conditions participating together: We thought participants in 60-min condition would be confused why they were still taking part in the study when a person sitting next to them—who unbeknownst to them was in the 30-min condition—had already finished.

[4]The CB and FAE results are reported elsewhere (Author Citation 1, 2014).

[5]The data for those who did not return for their second visit (21%) were included and analyzed as part of the single-play condition. The repeated-play-return and the repeat-play non-return groups did not differ on any personality or demographic variables measured in this project (nonsignificant independent-sample t tests are reported elsewhere; Author Citation 1, 2014).

[6]In Figure 3, the only notable between-subjects difference, at 8-week posttest, between 60-min (M = 1.21, SD = 0.94) and 30-min play (M = 1.09, SD = 0.92) was not significant, $t(483) = -1.44$, $p = .15$.

[7]The pretest versus 8-week posttest difference was not significant, $t(232) = .91$, $p = .36$.

[8]Using Greenhouse-Geisser correction does not substantively change these results.

[9]As in Experiment 1, using Greenhouse-Geisser correction does not change these results.

[10]At 8 weeks, single play did not differ from repeated play, $t(414) = 1.19$, $p = .24$.

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[11]We also found a significant duration by repetition interaction, $F(1, 399) = 5.57$, $p = .02$, $\eta_p^2 = .01$: Repetition effects were more comparable during 60-min play, but for 30-min play, contrary to what was expected, repeated play increased BBS relative to single play.

Table 1

Means, Standard Deviations, and Correlations between All Variables in Each Experiment

Experiment 1	*M*	*SD*	1	2	3	4	5	6	7	8	9	10
1. Training	1.46	0.50	–									
2. Repetition	1.46	0.50	0.08	–								
3. Duration	1.57	0.50	-0.07	-0.01	–							
4. Location	1.55	0.50	-0.02	0.02	-0.03	–						
5. Know pretest	1.03	0.98	-0.02	-0.01	-0.04	-0.12**	–					
6. Know last posttest	1.43	1.04	-0.17**	0.14**	0.00	-0.18**	0.29**	–				
7. Know 8-week post	1.16	0.93	-0.06	0.14**	0.07	-0.13**	0.30**	0.35**	–			
8. Miti pretest	2.78	3.26	-0.06	0.03	-0.01	-0.07	0.07	0.14**	0.11*	–		
9. Miti last posttest	1.88	2.97	0.00	-0.13**	0.04	0.00	-0.04	0.05	-0.03	0.27**	–	
10. Miti 8-week post	1.63	2.61	-0.02	0.02	0.03	-0.03	0.04	0.04	0.06	0.21**	0.29**	–
Experiment 2	*M*	*SD*	1	2	3	4	5	6	7	8	9	10
1. Feedback	1.57	0.50	–									
2. Repetition	1.39	0.49	-0.14**	–								
3. Duration	1.54	0.50	0.12**	-0.05	–							
4. Location	1.53	0.50	-0.02	-0.05	0.01	–						
5. Know pretest	1.04	0.94	-0.04	0.04	0.05	-0.06	–					
6. Know last posttest	1.47	1.02	-0.01	0.17**	-0.02	-0.12**	0.18**	–				
7. Know 8-week post	1.11	0.94	-0.09	0.12*	0.09	-0.10	0.27**	0.39**	–			
8. Miti pretest	2.55	2.93	0.00	0.07	-0.03	0.04	0.04	0.02	0.09	–		
9. Miti last posttest	1.69	3.04	-0.01	0.14**	-0.07	-0.05	-0.03	0.05	-0.06	0.33**	–	
10. Miti 8-week post	1.66	2.78	0.04	-0.06	0.00	0.04	0.02	0.02	0.05	0.36**	0.30**	–
Experiment 3	*M*	*SD*	1	2	3	4	5	6	7	8	9	10
1. Learn. environment	1.59	0.49	–									
2. Repetition	1.37	0.48	-0.17**	–								
3. Duration	1.65	0.48	-0.08	-0.18**	–							
4. Location	1.52	0.50	0.00	0.03	0.05	–						
5. Know pretest	1.55	1.07	-0.06	0.06	-0.07	-0.09*	–					
6. Know last posttest	1.71	1.01	0.01	0.22**	-0.09*	-0.17**	0.37**	–				
7. Know 8-week post	1.43	1.01	0.04	0.08	0.00	-0.15**	0.24**	0.31**	–			
8. Miti pretest	6.13	6.08	0.02	-0.09*	0.02	-0.13**	0.06	-0.05	0.03	–		
9. Miti last posttest	4.57	6.25	0.02	-0.05	0.02	-0.09*	0.10*	-0.05	0.11*	0.54**	–	
10. Miti 8-week post	3.72	5.56	-0.07	0.03	-0.02	-0.06	-0.02	-0.02	0.01	0.32**	0.40**	–

Note. *Miti* stands for BBS mitigation; *Know* stands for BBS knowledge.
* $p < .05$ (two-tailed). ** $p < .01$ (two-tailed).

Table 2

The Overview of the Argument Presented in the Paper and the Three Experiments

Problem	Solution	Our Approach
BBS – the unconscious tendency to value one's knowledge, experiences, and introspections over the knowledge, experiences, and introspections of others BBS compromises quality decision making and makes people blind to own biases BBS mitigation is difficult because people • are not aware they are biased • do not see evidence of own biases • become defensive when told they are biased Thus, people need to observe themselves being biased without defensiveness being triggered	We developed a bias-training serious video game, which: • offered players opportunities to demonstrate bias • players' biased decisions were revealed to them either implicitly through a reward structure of the game (e.g., through loss of points for biased decisions) and/or explicitly through bias education. By observing how their biases had cost them points—or even the entire game—players could more easily evaluate their own actions in the game as demonstrably biased, thereby sensitizing them to their own BBS.	In Experiment 1, we manipulated Training (implicit vs. hybrid) In Experiment 2, we manipulated Feedback (JIT vs. delayed) + we kept hybrid training constant In Experiment 3: we manipulated Learning Environment (single-player vs. multiplayer) + we kept hybrid training and JIT feedback constant In addition, in all experiments we manipulated Repetition (single vs. repeated play) and Duration (30 min vs. 60 min) and examined participants' responses at 3 points in time: pretest, last posttest, 8-week posttest

Table 3

Representative Results across Experiments

	Experiment 1	Experiment 2	Experiment 3
Hypotheses related to game mechanics:	H1: Hybrid (vs. implicit) training (a) increases BBS knowledge and (b) reduces BBS. – H1(a) supported, but over time hybrid (vs. implicit) training improved knowledge more only at last posttest. – H1(b) not supported.	H4: JIT (vs. delayed) feedback (a) increases BBS knowledge and (b) reduces BBS. – Not supported.	H5: Single-player (vs. multiplayer) learning environment (a) increases BBS knowledge and (b) reduces BBS. – Not supported.
H2: Repeated (vs. single) play (a) increases BBS knowledge and (b) reduces BBS.	– H2(a) supported; – H2(b) partially supported: Repeated (vs. single) play reduced BBS only at last posttest.	– Supported.	– Supported (but over time repeated play increased BBS knowledge more than single play only at last posttest)
H3: Longer (vs. shorter) duration (a) increases BBS knowledge and (b) reduces BBS.	– Not supported.	– Not supported.	– Not supported.
RQ: What are the temporal trajectories of BBS (a) knowledge and (b) mitigation?	BBS Knowledge: – Knowledge improved at last posttest but then decayed at 8 weeks. However, the effects of training, repetition, and to some extent duration, were able to offset the decay in knowledge at 8-weeks. At 8 weeks, hybrid training, repeated play, and 60-min game, although still resulting in some decay relative to the last posttest, improved BBS knowledge relative to the pretest. BBS Mitigation: – Regardless of condition, MACBETH reduced BBS from pretest to last posttest, and this reduction in bias remained the same at 8-week posttest.	BBS Knowledge: – BBS knowledge had initially increased from pretest to last posttest but then decayed to almost pretest levels weeks. BBS Mitigation: – Regardless of condition, BBS reduced linearly over time. – A significant time by repetition interaction indicated repeated play reduced BBS linearly from pretest to last posttest, and from last posttest to 8-week posttest where it caught up with the effects of the single play.	BBS Knowledge: – Regardless of experimental condition, BBS knowledge increased from pretest to last posttest but then decayed at 8 weeks. – Time by repetition interaction indicated repeated play increased BBS knowledge from pretest to last posttest, but knowledge decayed at 8 weeks. BBS Mitigation: – Regardless of condition, MACBETH reduced BBS linearly over time.

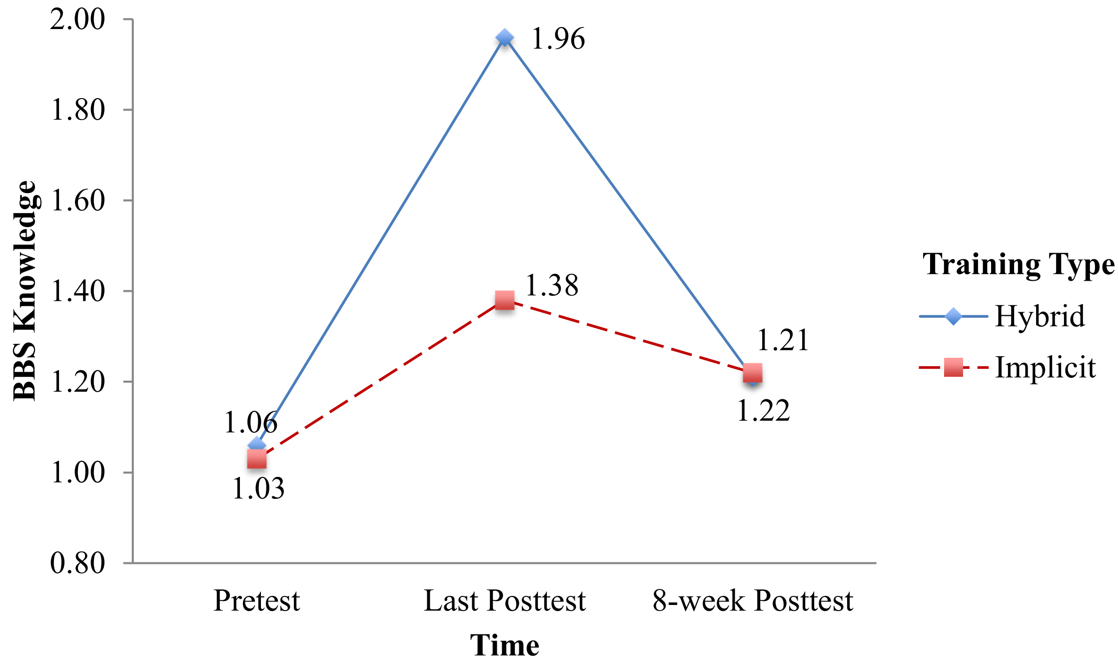


Figure 1. Time by training interaction on BBS knowledge (Experiment 1).

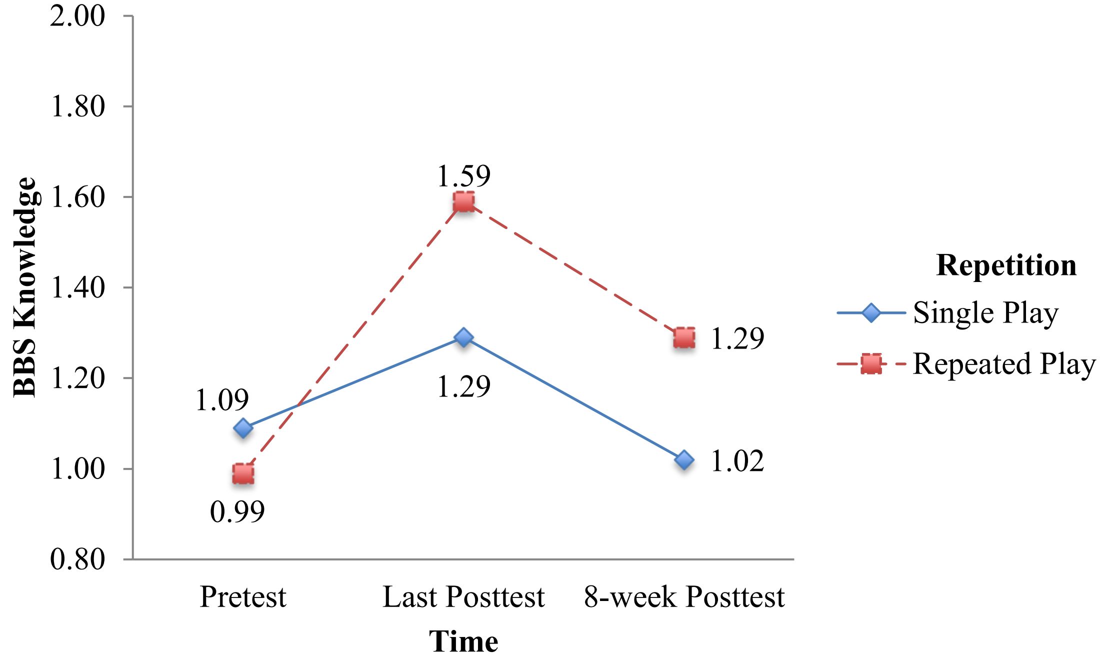


Figure 2. Time by repetition interaction on BBS knowledge (Experiment 1).

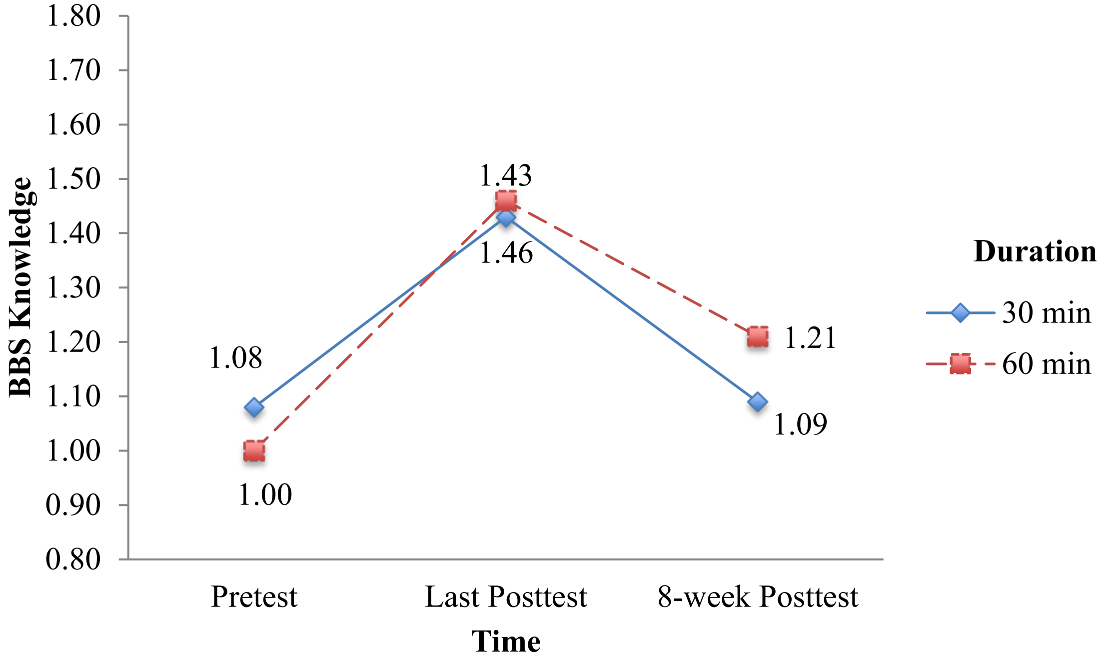


Figure 3. Time by duration interaction on BBS knowledge (Experiment 1).

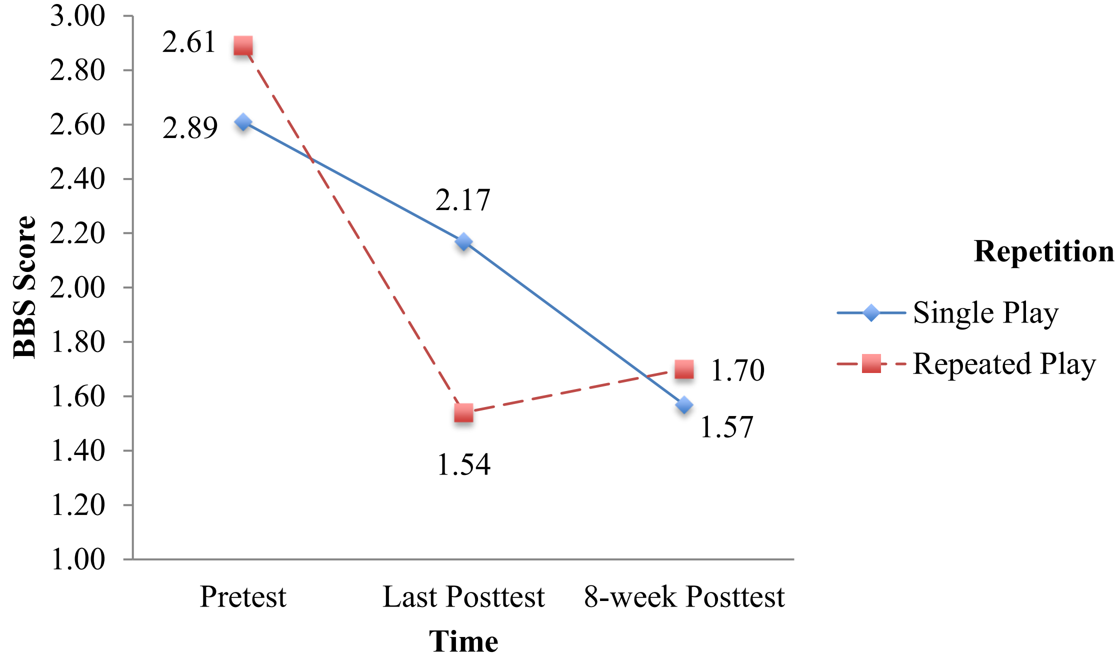


Figure 4. Time by repetition interaction on BBS (Experiment 1).

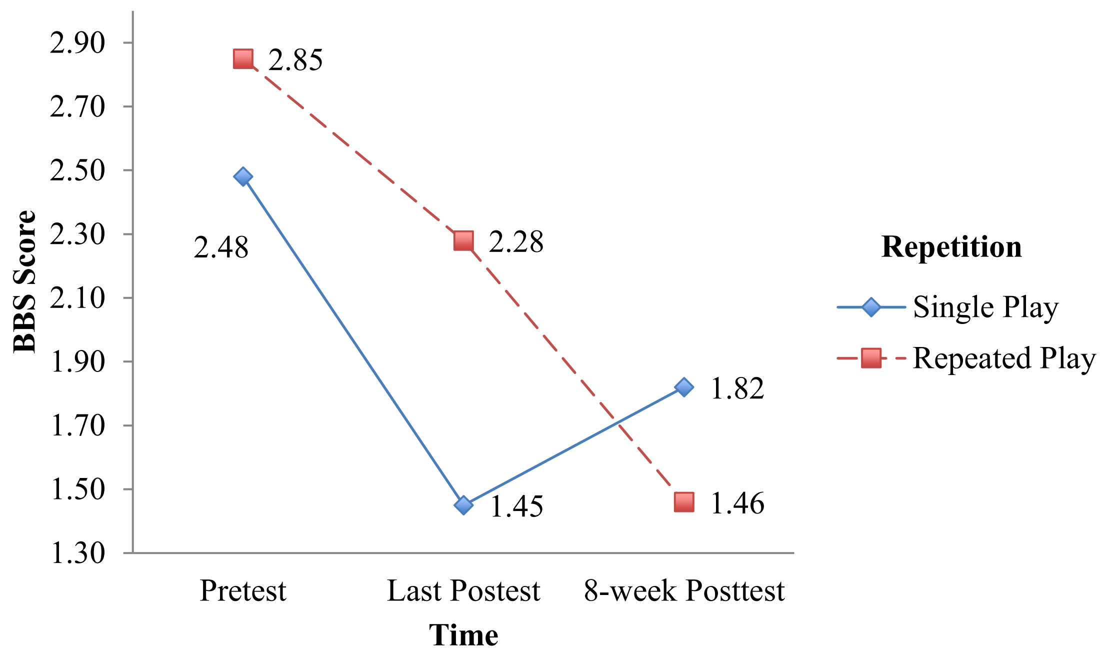


Figure 5. Time by repetition interaction on BBS (Experiment 2)

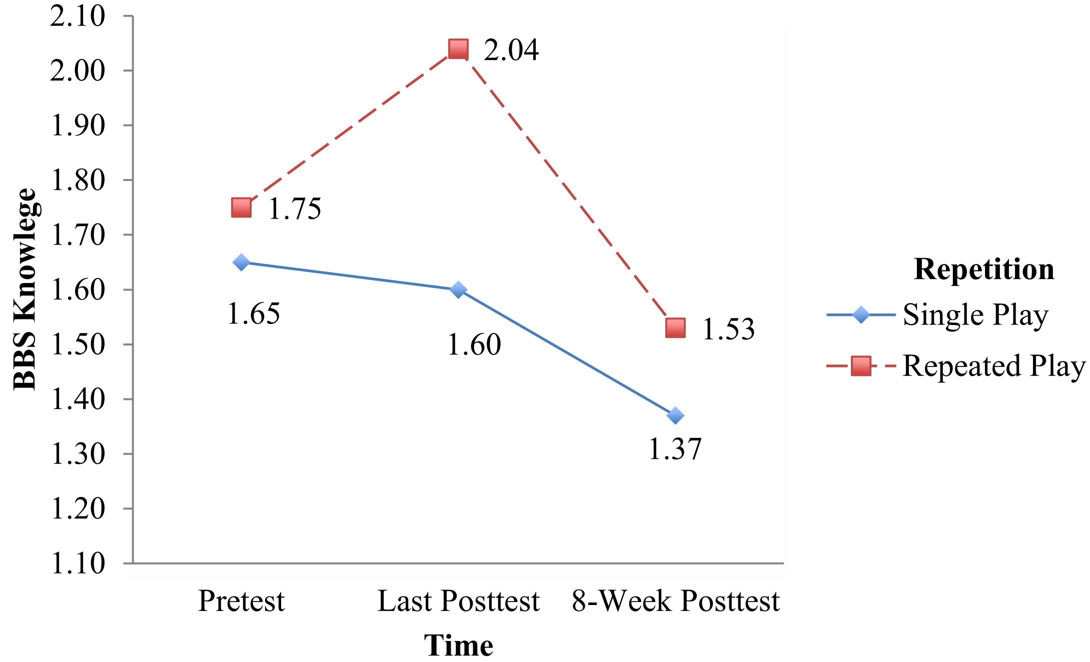
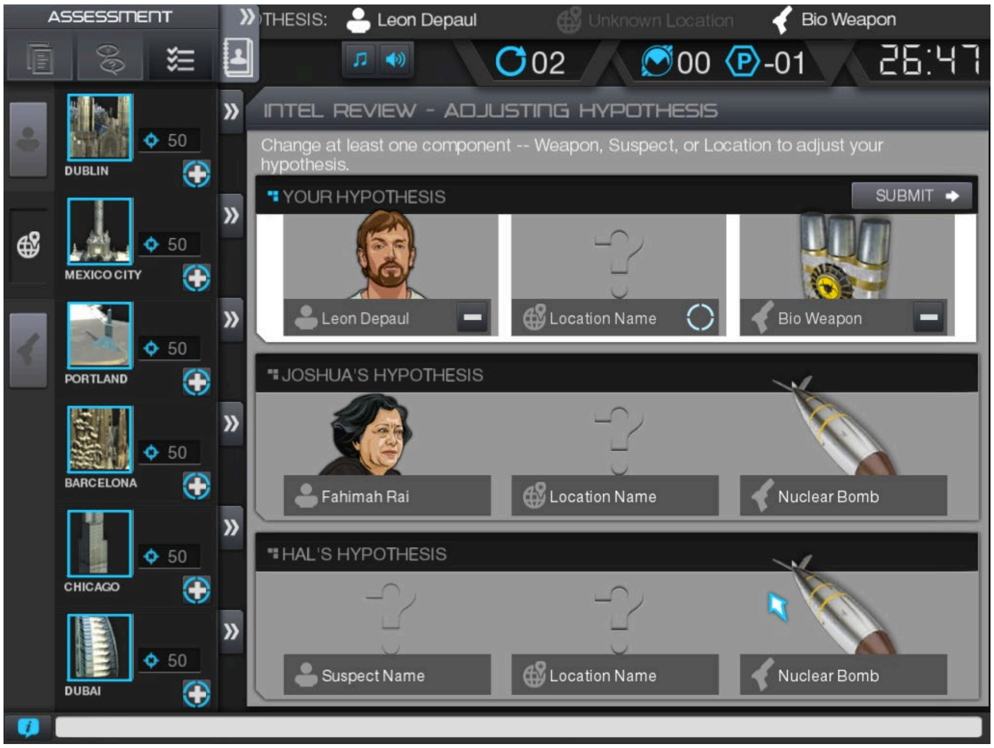


Figure 6. Time by repetition interaction on BBS knowledge (Experiment 3).

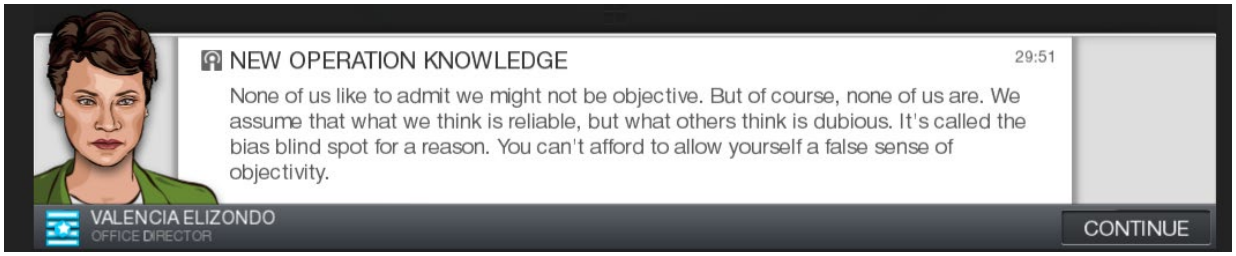
Appendix A

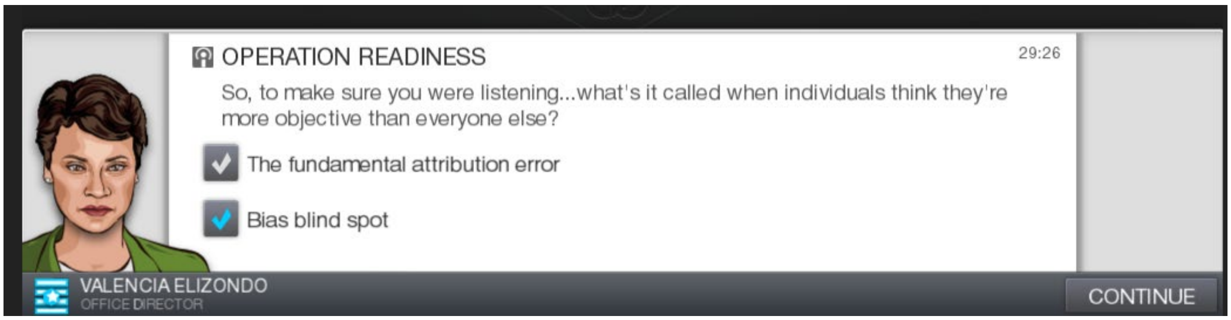
Choosing a suspect, location, and weapon (top panel) and the news report for the concluding cinematic (bottom panel) in MACBETH



Appendix B

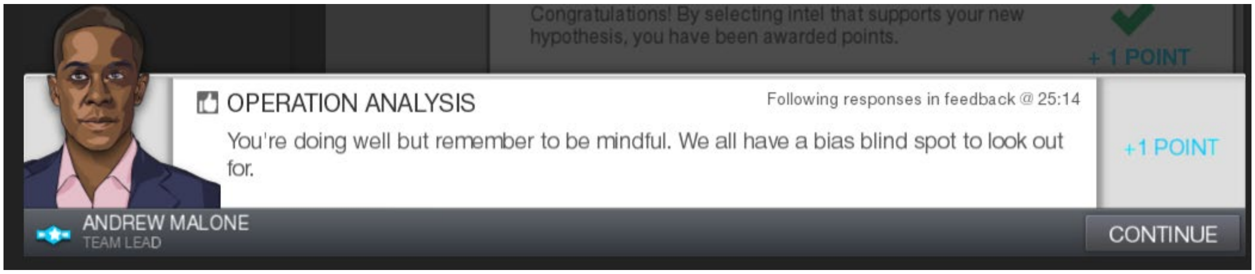
BBS training and quiz in MACBETH

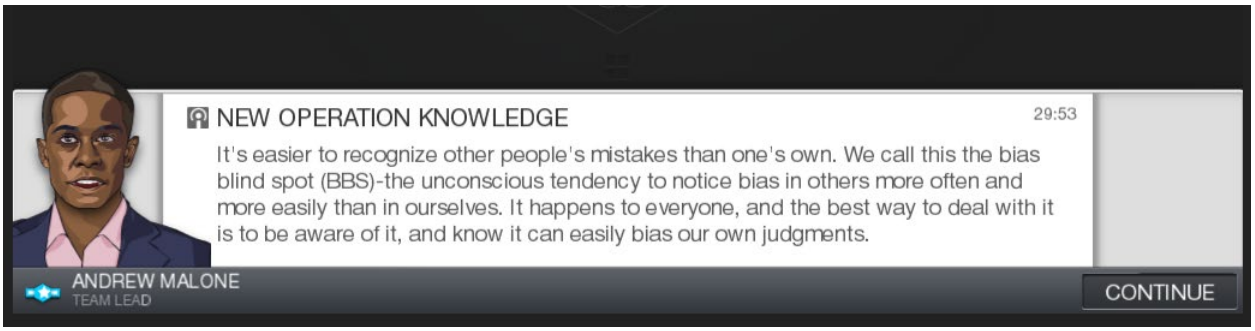




Appendix C

BBS feedback





Appendix D

Multiplayer interaction in game