Attention, Perception, & Psychophysics
2010, 72 (4), 1120-1129
doi:10.3758/APP.72.4.1120

Video game players show more precise multisensory temporal processing abilities

Sarah E. Donohue, Marty G. Woldorff, and Stephen R. Mitroff
Duke University, Durham, North Carolina

Recent research has demonstrated enhanced visual attention and visual perception in individuals with extensive experience playing action video games. These benefits manifest in several realms, but much remains unknown about the ways in which video game experience alters perception and cognition. In the present study, we examined whether video game players' benefits generalize beyond vision to multisensory processing by presenting auditory and visual stimuli within a short temporal window to video game players and non–video game players. Participants performed two discrimination tasks, both of which revealed benefits for video game players: In a simultaneity judgment task, video game players were better able to distinguish whether simple visual and auditory stimuli occurred at the same moment or slightly offset in time, and in a temporal-order judgment task, they revealed an enhanced ability to determine the temporal sequence of multisensory stimuli. These results suggest that people with extensive experience playing video games display benefits that extend beyond the visual modality to also impact multisensory processing.

We are constantly bombarded with both visual and auditory stimuli, all of which must be rapidly processed to construct a veridical representation of our environment. Although this is seemingly accomplished with ease, a series of complicated processes and principles have been shown to underlie multisensory perception (see Driver & Noesselt, 2008, and Stein & Stanford, 2008, for reviews). For example, one fundamental principle of multisensory processing is that input from different modalities must be perceived in temporal synchrony to be bound into a single multisensory object (e.g., Meredith, Nemitz, & Stein, 1987; Stein & Meredith, 1993). This can be easily evidenced by focusing on the effects of temporal *asynchrony*, when the stimulus components from different modalities occur separated by too large of a temporal gap, such as in a badly dubbed movie or when computer processors temporarily freeze, resulting in a delay between what is typed (i.e., the tactile input) and what appears (i.e., the visual display). It certainly can be distracting when stimuli from multiple modalities are temporally misaligned; however, how far apart in time do these stimuli need to be before we begin to notice such temporal discrepancies? Or, conversely, how far apart in time can multisensory information be while still being bound into one perceptual representation? Moreover, in a complex multisensory world in which it is of fundamental importance to be able to accurately link corresponding cross-modal inputs and separate noncorresponding ones, how might the ability to accurately make such links be affected by an individual's prior perceptual experiences?

Although not explicitly, most prior work has appeared to assume that there is relatively little difference across individuals in their temporal window of integration (i.e., how close together in time stimuli must occur in order to be perceptually integrated into a single, multisensory object). This is manifested in that individual participant data are rarely reported (but see Stone et al., 2001; Vatakis, Navarra, Soto-Faraco, & Spence, 2007), with most researchers not examining individual or group differences (e.g., Spence, Shore, & Klein, 2001; van Wassenhove, Grant, & Poeppel, 2007; Zampini, Guest, Shore, & Spence, 2005). Might each individual's prior experiences and life history influence his or her perceptual processing? Extreme cases suggest that it would, revealing, for example, altered behavior (Putzar, Goerendt, Lange, Rösler, & Röder, 2007) and differential neural processing in auditory-attention tasks in early-blind participants (Liotti, Ryder, & Woldorff, 1998) and differential neural firing patterns (for sensory integration) in animals deprived of early sensory input (Carriere et al., 2007; Ghoshal, Pouget, Popescu, & Ebner, 2009). Given that differential life-related perceptual experiences can lead to altered neural activity and perceptual abilities, here we ask whether certain individuals with a specific type of experience (extensive video game playing) have a more fine-tuned sense of temporal synchrony that enables a greater ability to notice slight asynchronies.

Tools to Distinguish Multisensory Temporal Processing

To delineate individuals' temporal window of integration, we used two standard, well-established tasks: the simultaneity judgment task and the temporal-order judgment task. In multisensory simultaneity judgment tasks, participants are presented with stimuli from two different

S. E. Donohue, sarah.donohue@duke.edu

modalities that can occur either simultaneously or with various temporal offsets. The temporal offsets typically occur in both directions (i.e., a visual stimulus could proceed or follow an auditory stimulus) at varying stimulus onset asynchronies (SOAs). The participants are asked simply to report whether the stimuli appeared simultaneously or asynchronously (e.g., Stone et al., 2001). Likewise, in multisensory temporal-order judgment tasks (e.g., Zampini, Shore, & Spence, 2003), participants are presented with stimuli that either occur simultaneously or are offset by various SOAs and are asked to judge which modality came first (e.g., was the auditory stimulus presented first, or was the visual stimulus presented first?). There is clearly some redundancy between the temporal-order and simultaneity judgment tasks, but subtle differences in their effects suggest that they may operate by somewhat different mechanisms. As such, it is beneficial to employ both of them to assess cross-modal processing (see van Eijk, Kohlrausch, Juola, & van de Par, 2008; and Vatakis, Navarra, et al., 2007, for discussions).

In simultaneity judgment tasks, when stimuli in different modalities (e.g., auditory and visual) are presented at offsets at or close to physical simultaneity, participants typically judge these stimuli to be simultaneous. As the SOAs between the stimuli increase, the reports of perceptual simultaneity gradually decrease, falling off more and more as the stimuli get farther away from physical simultaneity. This task is particularly sensitive to temporal offsets at longer SOAs, highlighting those SOAs at which the participants determine the stimuli to be temporally disparate. On the basis of this task, auditory and visual stimuli appear to be integrated into a single perceptual representation at SOAs from physical simultaneity (i.e., 0 msec apart) up to ~150–200 msec, after which the two stimuli are perceived as distinct (Schneider & Bavelier, 2003; Zampini, Guest, et al., 2005). Accordingly, this temporal window of around 150 msec has been viewed as reflecting the typical temporal window of multisensory integration.

Temporal-order judgment tasks, in contrast to simultaneity judgment tasks, are most informative at short SOAs (e.g., 50 msec), at which it is difficult to distinguish which stimulus came first (e.g., Zampini et al., 2003). Performance is typically very good at longer SOAs (where it is obvious which stimulus appeared first), but individual differences can potentially arise at the more difficult, shorter SOAs. Together, simultaneity and temporal-order judgment tasks provide a complete picture of the temporal intervals at which information can be integrated or discriminated, and we implemented both here to best assess an individuals' temporal window of integration.

Finding Individual Differences in Multisensory Temporal Integration

Although the SOAs over which cross-modal stimuli are integrated into one perceptual representation differ across tasks and modalities (see, e.g., Zampini, Brown, et al., 2005; Zampini et al., 2003), the temporal window of multisensory integration is generally a reliable and replicable effect, with the likelihood of integration decreasing with increasing SOA (e.g., Spence et al., 2001; Stone et al., 2001; Vatakis, Bayliss, Zampini, & Spence, 2007; Vatakis & Spence, 2006). However, there is some evidence that temporal integration can be altered. In one study, when participants were repeatedly exposed to audio–visual stimuli with a given temporal offset, their subsequent simultaneity judgments were biased toward that offset (Vroomen, Keetels, de Gelder, & Bertelson, 2004). Additionally, Harrar and Harris (2008) demonstrated that repeated preexposure is not modality specific, in that pre-exposure to temporally offset stimuli (by 100 msec) in either the auditory/visual, visual/tactile, or auditory/tactile modalities can shift the perception of simultaneity for audio–visual stimuli in the direction of that temporal offset. These two examples offer an intriguing suggestion that temporal integration can be manipulated by prior experiences.

Beyond the effects of immediate malleability of sensory perception, longer-term malleability has also been demonstrated. For example, extensive experience with a specific set of frequencies in an auditory discrimination task has been shown to shape neuronal responses and cortical organization in nonhuman primates (Recanzone, Schreiner, & Merzenich, 1993). More recently, striking evidence of long-term perceptual malleability in healthy adult humans has come from studies in which the effects of extensive action video game experiences were examined (e.g., Castel, Pratt, & Drummond, 2005; Feng, Spence, & Pratt, 2007; Green & Bavelier, 2003, 2006a, 2006b, 2007; Quaiser-Pohl, Geiser, & Lehmann, 2006; West, Stevens, Pun, & Pratt, 2008). Action video game players (VGPs) have been shown to have, among other benefits, heightened visual acuity (Green & Bavelier, 2007), enhanced contrast sensitivity (Li, Polat, Makous, & Bavelier, 2009), an improved ability to simultaneously track multiple moving visual items (Green & Bavelier, 2006b), better spatial abilities (e.g., Quaiser-Pohl et al., 2006), enhanced divided attention abilities (e.g., Greenfield, DeWinstanley, Kilpatrick, & Kaye, 1994), and improved eye–hand motor coordination (e.g., Griffith, Voloschin, Gibb, & Bailey, 1983). Non–video game players (NVGPs) who are trained on action video games for a relatively short time period reveal some VGP-like benefits, supporting the claim that the observed benefits arises from experience and not from preexisting predilections (e.g., De Lisi & Cammarano, 1996; De Lisi & Wolford, 2002; Dorval & Pépin, 1986; Green & Bavelier, 2003, 2006a, 2006b, 2007; McClurg & Chaille, 1987; Okagaki & Frensch, 1994; but see Boot, Kramer, Simons, Fabiani, & Gratton, 2008; Gagnon, 1985; Rosenberg, Landsittel, & Averch, 2005; Sims & Mayer, 2002).

Video games are inherently multisensory, with first-person shooter and other action games often having both auditory and visual cues that are relevant to an appropriate behavioral response. High-action first-person shooter games combine intense visual graphics with corresponding and informative auditory cues and feedback and can involve multiplayer interactions wherein players communicate with each other via auditory conversations. Given this multisensory nature of the games, it seems quite possible that the VGPs' benefits would extend to multisensory processing, such as by affecting individuals' window of multisensory temporal integration. Specifically, given that action video games bombard the players with multisensory stimuli that must be processed rapidly and accurately, it seems reasonable to hypothesize that VGPs would be better able to parse audio–visual information when the audio and visual stimuli occur closely together in time.

In the present experiment, we tested VGPs and NVGPs on both a simultaneity judgment task and a temporal-order judgment task, which allowed us to simultaneously ask two novel questions: Do individual differences exist for multisensory temporal integration windows, and do video game playing benefits extend beyond vision to the realm of multisensory processing? In the simultaneity judgment task, we hypothesized that the VGPs would show a narrower window of integration, being less likely to judge stimuli as occurring simultaneously when they were indeed physically asynchronous. That is, we predicted that the VGPs would be more accurately able to distinguish asynchronies between closely occurring visual and auditory stimuli. Likewise, for the temporal-order judgment task, we predicted that the VGPs would be better able to distinguish which stimulus (auditory or visual) occurred first at small SOAs, thereby also revealing enhanced perceptual discrimination abilities. On the other hand, we live in a complex world that is inherently multisensory, and so the NVGPs should have abundant exposure to integrating visual and auditory information. Thus, another possibility was that there would be little to no benefit from playing action video games to multisensory temporal integration.

METHOD

Participants

Forty-five male members of the Duke University community participated. On the basis of assessments of their prior gaming experiences, we categorized these participants into three groups: 18 VGPs (mean age = 20 years, *SD* = 2.5), 18 NVGPs (mean age = 20.6 years, *SD* = 3.5), and 9 *other* participants whose experience with video games fell between these two categorical levels of gaming experience, which are described below (mean age = 19.2 years, *SD* = 1.4). Six additional participants (1 VGP, 4 NVGPs, and 1 *other*) were excluded because of poor behavioral performance, indicated by having points of subjective simultaneity (see the Gaussian and Sigmoid fitting subsections of the Results section) in either task that exceeded the range of SOAs tested. Similar to previous experiments (e.g., Green & Bavelier, 2006a), no female participants were included because of difficulty in finding sufficient numbers of females with extensive gaming experience. Participants received either course credit or monetary compensation.

Video game experiences were assessed via a postexperiment questionnaire that asked about the length and amount of experience within several video game genres, as well as via a self-report of level of expertise with each genre. The questionnaire served two purposes. First, it provided a means to classify the participants as a VGP, an NVGP, or an *other*. NVGPs were defined as those participants who had 0 h per week of first-person shooter experience in the past 6 months, as well as having less than 1.5 h per week within the past 6 months of real-time strategy and sports games (NVGP mean = 45 min per week). VGPs were defined as having at least 2 h per week of first-person shooter experience in the past 6 months, as well as playing any type of action game (including first-person shooter, real-time strategy, and sports games) for a minimum of 4.5 h per week within the past 6 months (VGP mean = 11 h per week). Additionally, the VGPs had all played first-person shooter games for at least 5 h per week at some point in their lives. The additional 9 participants were excluded from the majority of the analyses, which were categorical VGP–NVGP comparisons, because their video game experiences fell between these two criteria; however, their data were included in the correlational analyses (see below and the Results section).

The second purpose of the video game questionnaire was to provide a means to quantify a participant's amount of gaming experience on a continuous scale. On the basis of the answers for each video game genre, we calculated for each participant an overall gaming score (i.e., a number between 0 and 317) that accounted for general gaming experience and expertise across all genres of video games. This score was used in the correlational analyses (see the Results section).

Apparatus

The participants sat approximately 57 cm from a 19-in. CRT monitor in a quiet testing room. The auditory stimuli were presented centrally through two speakers evenly spaced to the left and right of the monitor, and the presentation of the visual and auditory stimuli was controlled by Presentation (Neurobehavioral Systems, Albany, CA) on a Dell PC.

Stimuli

Each trial comprised a visual black-and-white square checkerboard pattern (5º × 5º, 33-msec duration) and an auditory tone (33-msec duration, 60 dBSL, 5 msec rise-and-fall time, 1200 Hz). Across trials, the visual and auditory stimuli appeared equally often with the following SOAs, in milliseconds, where negative represents auditory first, positive indicates auditory second (i.e., visual first), and 0 represents physical simultaneity: −300, −250, −200, −150, −100, −50, 0, 50, 100, 150, 200, 250, 300. The visual stimuli were either presented in the midline for a given block (see Figure 1), with the visual stimulus appearing centered 3.4º below a fixation cross, or presented laterally, with the visual stimulus appearing 12.3º to the left or right of the midline and 3.4º below the level of the fixation cross. The auditory stimulus was always presented centrally, regardless of the position of the visual stimulus. The variation of the spatial location of the visual stimulus was done for two reasons. First, it has been previously shown that the spatial position of the multisensory stimuli can influence the judgments of simultaneity and temporal order, with increased spatial separation yielding a decreased perception of simultaneity (e.g., Zampini, Guest, et al., 2005). Since the VGPs had not previously been tested in multisensory paradigms of this nature, we wished to determine whether the spatial separation between the stimuli would have more of an effect on the judgments for one group of participants than on those of the other. Second, since VGPs have been previously shown to have particularly enhanced visual resolution and attention in the periphery (e.g., Green & Bavelier, 2003, 2007), it is possible that differences between the VGPs and the NVGPs would occur mainly or even only for stimuli

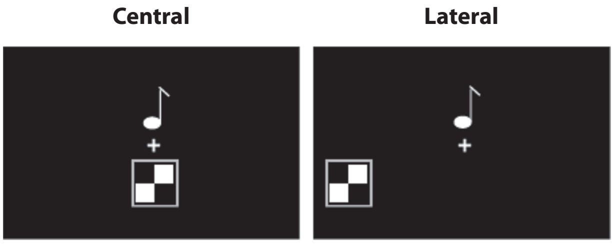

Figure 1. Experimental task. Depiction of experimental stimuli in the central and lateral conditions (left-side stimulus shown here). The auditory stimulus (represented here by the symbol for a musical note) was presented centrally, and the visual stimulus's location varied by block.

presented in the periphery. In a given block, the spatial position of the visual stimuli was kept constant (e.g., presented only on the left for a given block), so that the participants did not have to spatially shift attention across sides from trial to trial.

Procedure

Each participant completed both a simultaneity judgment task and a temporal-order judgment task, with the task order counterbalanced across participants. In the simultaneity judgment task, the participants were asked to judge whether the auditory and visual stimuli were presented simultaneously or asynchronously and to indicate their response with a keypress (1, *simultaneous*; 2, *nonsimultaneous*) using a standard keyboard number pad. In the temporal-order judgment task, the participants were asked to judge whether the auditory or the visual stimulus was presented first, again indicated with a keypress (1, *auditory first*; 2, *visual first*). The participants were instructed to be as accurate as possible, and there was no response time limit. After each trial, the participants pressed the "0" key on the number pad to advance to the next trial. Each block comprised 12 trials at each SOA, for a total of 156 randomly presented trials per block. There were four blocks per task (two with central, one with left, and one with right visual presentation), resulting in 624 total trials per task. Block order was randomized for each participant. Prior to the start of each task, the participants completed a practice block of 12 trials.

RESULTS

Simultaneity Judgment Task

The primary measure of interest was the proportion of *simultaneous* responses at each audiovisual SOA. These proportion values were calculated for each SOA for each participant, separately for the central and lateral conditions. Preliminary analyses revealed no differences between the left and right lateral visual presentation trials, and so all lateral data were collapsed over left–right position. Because the participants were instructed to prioritize accuracy over response time and no response time limits were employed, no response time effects were found for either task, and therefore, response times will not be discussed further.

Response distributions. To examine the effect of lateralization on simultaneity judgments, we conducted a $2 \times 2 \times 13$ mixed-design ANOVA on the percentage of *simultaneous* responses, with VGP status (VGP vs. NVGP) as a between-subjects factor and stimulus position (central vs. lateral) and SOA (each of the 13 intervals) as within-subjects factors. These analyses revealed main effects of SOA [$F(1,12) = 105.33$, $p < .001$] and an interaction of SOA and VGP status [$F(1,12) = 3.84$, $p < .001$], with only a trend toward significance for the effect of stimulus position [$F(1,34) = 3.13$, $p = .09$]. Furthermore, the interaction of VGP status and position was not significant. Because the position of stimuli had no significant effect on the response pattern, subsequent analyses were collapsed across central and lateral conditions (Figure 2A). As can be seen in Figures 2A–2D and as is discussed below, the primary differences between the VGPs and the NVGPs occurred when the visual stimulus came first. Overall, however, the VGPs showed a more narrow perceptual distribution function with more precise judgments at the various SOAs.

Planned post hoc *t* tests revealed that the VGPs differed significantly from the NVGPs at the visual-first SOAs of +150 msec [$t(34) = 2.50$, $p = .02$], +200 msec [$t(34) = 2.23$, $p = .03$], +250 msec [$t(34) = 2.93$, $p = .006$], and +300 msec [$t(34) = 2.52$, $p = .02$], and marginally differed from the NVGPs at +100 [$t(34) = 1.96$, $p = .06$]. For each of these SOAs, the VGPs more accurately reported the trials as *nonsimultaneous* than did the NVGPs.

Gaussian fitting. To further characterize potential differences between the VGPs and the NVGPs, we fit each participant's data to a Gaussian function. The results of this fitting (and subsequent averaging for the VGP and NVGP groups) are shown in Figure 2B. As had been done with the raw data above, the fitted data for each participant were analyzed in a 2×13 (VGP status $\times$ SOA) ANOVA. This analysis revealed a main effect of SOA [$F(1,12) = 136.62$, $p < .001$], and an SOA $\times$ VGP status interaction [$F(1,12) = 5.08$, $p < .001$]. Subsequent planned *t* tests revealed that, as was the case above, the VGPs were more accurate than NVGPs (i.e., they were more likely to correctly judge the SOAs as nonsimultaneous) at the SOAs of +100 msec [$t(34) = 2.38$, $p = .02$], +150 msec [$t(34) = 2.62$, $p = .01$], +200 msec [$t(34) = 2.71$, $p = .01$], +250 msec [$t(34) = 2.79$, $p = .009$], and +300 msec [$t(34) = 2.82$, $p = .008$].

Point of subjective simultaneity. We calculated each participant's point of subjective simultaneity—the SOA at which the participant was the most likely to judge the auditory and visual stimuli as occurring simultaneously. An ideal observer would have a point of subjective simultaneity at an SOA of 0 msec, and an auditory-first biased observer would have a negative value on the scale used here. That is, a point of subjective simultaneity of −50 msec would mean that the observer would be most likely to judge the auditory and visual stimuli as occurring simultaneously when the auditory stimulus preceded the visual by 50 msec. Using each participant's data that had been fit to a Gaussian function, we calculated the mean and the standard deviation of the distribution (Zampini, Shore, & Spence, 2005). The resulting mean gave the point of subjective simultaneity as it occurs at the SOA with the most *simultaneous* responses, and the resulting standard deviation indicated the spread of the participant's responses. This spread of responses served as a proxy for how difficult the participant found the task: The narrower their curve was (i.e., the smaller the standard deviation), the easier the task was for them.

The VGPs and NVGPs produced significantly different group averages for their points of subjective simultaneity (VGP, $M = -15.1$ msec; NVGP, $M = +26.6$ msec) [$t(34) = 3.09$, $p < .005$], such that the VGPs were biased toward perceiving auditory stimuli coming first as simultaneous, and the NVGPs were biased toward perceiving visual stimuli coming first as simultaneous. In addition, the point of subjective simultaneity for the VGPs was closer to the veridical SOA of 0 msec (i.e., physical simultaneity) than was that of the NVGP; moreover, the VGPs' point of subjective simultaneity did not differ from 0 [$t(17) = 1.68$, $p = .11$], whereas the NVGPs' did [$t(17) = 2.64$, $p = .02$]. The VGPs also had a smaller within-subjects standard deviation (VGP, $M = 127.0$ msec; NVGP, $M = 160.3$ msec) [$t(34) = 2.32$, $p = .03$].

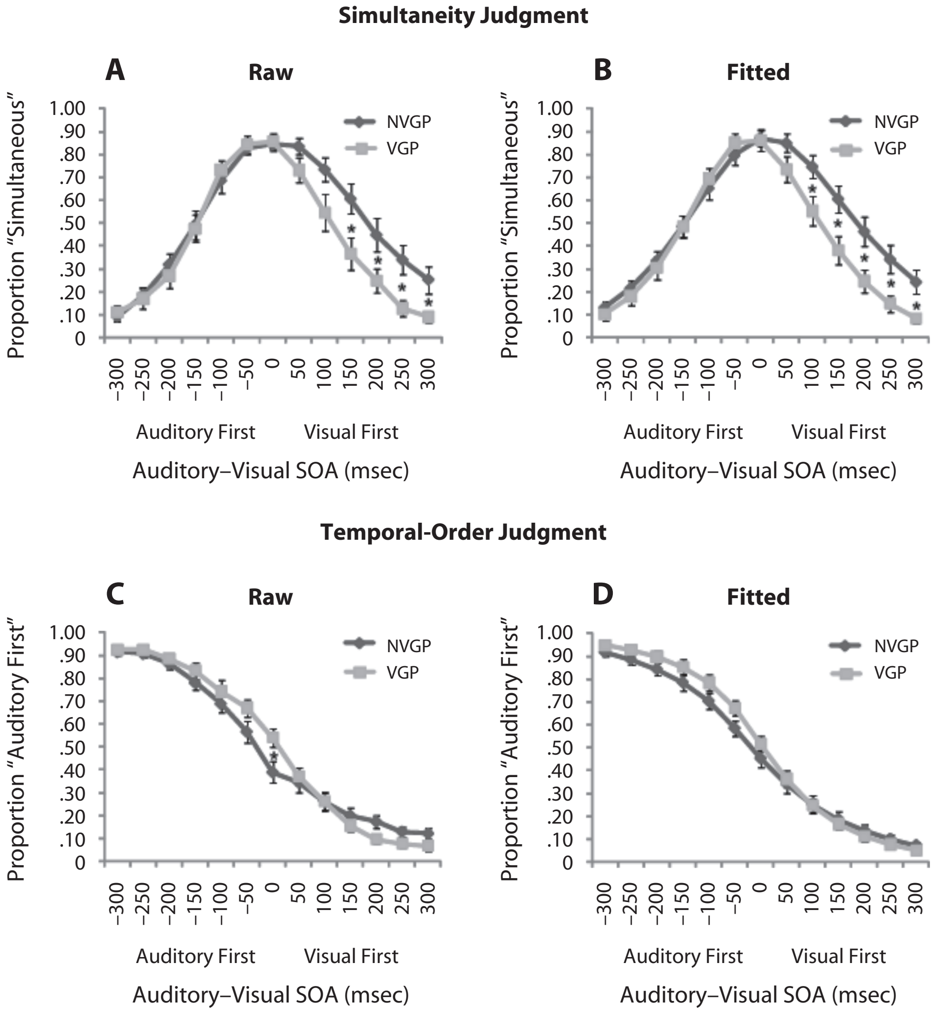

Figure 2. Results by task and data type. The raw and Gaussian-fitted conditions for the simultaneity judgment task (A and B) are plotted as the proportion of *simultaneous* responses, and the corresponding conditions for the raw and Sigmoid-fitted temporal-order judgment task (C and D) are plotted as the proportion of *auditory first* responses. Stimulus onset asynchronies (SOAs) represent the temporal asynchrony between the visual and auditory stimuli on a given trial, with negative values indicating that the auditory stimulus preceded the visual, positive values indicating that the auditory stimulus followed the visual, and 0 representing physical simultaneity. Asterisks denote significant differences between the VGPs and the NVGPs. Compared to the NVGPs, the VGPs were more accurate when the visual stimulus came before the auditory stimulus in the simultaneity judgment task and were more accurate at SOAs close to physical simultaneity in the temporal-order judgment task.

Temporal-Order Judgment Task

The proportion of *auditory first* judgments were calculated for each participant at each SOA in the central and lateral conditions. Preliminary analyses for the lateral visual presentation trials revealed no differences between the left and right locations, so all lateral data were collapsed over position. Here, we present analyses analogous to those conducted for the simultaneity judgment task, as well as additional analyses that reveal several nuanced differences.

Response distributions. A 2 × 2 × 13 ANOVA was conducted with VGP status (VGP vs. NVGP) as a between-subjects factor and position (central vs. lateral, collapsed across left and right) and SOA (each of the 13 intervals) as within-subjects factors. A significant main effect was observed for SOA [$F(1,12) = 260.45, p < .001$], as would be expected, with both the VGPs and the NVGPs indicating that their perception of temporal order differed as a function of SOA. There was also an SOA × VGP status interaction [$F(1,12) = 2.56, p < .005$], with the VGPs and NVGPs showing somewhat different response patterns, as is described below. There was no main effect of position, however, nor any interaction of position with any of the other factors. Because the position of the stimuli did not have a significant effect on judgments, the central and lateral conditions were collapsed for all subsequent analyses (Figure 2C).

To determine which specific SOAs were driving the SOA $\times$ VGP status interaction, post hoc *t* tests were conducted. These revealed that the VGPs and NVGPs significantly differed at 0 msec [$t(34) = 2.46$, $p = .02$], with the VGPs being closer to chance at this point, as should be the case for the forced-choice temporal-order judgment of two stimuli that were actually simultaneous. Additional marginally significant effects were found at +200 msec [$t(34) = 1.98$, $p = .056$], +250 msec [$t(34) = 1.73$, $p = .09$], and +300 msec [$t(34) = 1.73$, $p = .09$], with the VGPs being more likely to correctly report the auditory stimulus as coming last.

Sigmoid fitting. To further characterize the differences between groups, we fit the data from each participant to a sigmoid function. The averaged fitted data are shown in Figure 2D. We ran a 2 $\times$ 13 (VGP status $\times$ SOA) ANOVA for these data. This revealed a main effect of SOA [$F(1,12) = 455.55$, $p < .001$], again confirming that the participants distinguished the stimuli at the various SOAs, and an SOA $\times$ VGP interaction [$F(1,12) = 1.85$, $p = .04$]. This interaction derived from the VGPs' trend to be more accurate with their judgments than were the NVGPs, and therefore having a higher percentage of *auditory first* responses when the auditory stimulus physically came first and likewise, a higher percentage of *visual first* responses when the visual stimulus physically came first. None of the post hoc *t* tests revealed that the VGPs differed from the NVGPs at any particular SOA; however, at −50 msec, there was a trend for the VGPs to be more accurate at judging the auditory stimuli as coming before the visual [$t(34) = 1.89$, $p = .07$]. In addition, no differences in the slope were observed between groups ($p > .05$).

Point of subjective simultaneity and measure of just noticeable difference. As was done for the Gaussian fit data, we calculated the point of subjective simultaneity for each participant—the point at which the participants were most likely to report the stimuli as being simultaneous (here, the point at which the participants were least able to discriminate which stimulus came first). In addition, we calculated a just-noticeable-difference measure—the smallest SOA at which the participants were able to accurately distinguish which stimulus came first (e.g., Coren, Ward, & Enns, 2004; Poliakoff, Shore, Lowe, & Spence, 2006; Spence et al., 2001; Vatakis, Navarra, et al., 2007; Zampini, Brown, et al., 2005).

The differences between the VGPs and the NVGPs in these analyses tended to mirror those in the simultaneity judgment task, although they did not reach significance. More specifically, relative to the NVGPs, the VGPs had a point of subjective simultaneity that appeared to be slightly closer to veridical physical simultaneity, although the groups did not differ significantly from one another (VGP, $M = -1.47$ msec; NVGP, $M = -4.67$ msec). There was a slight trend for the just-noticeable difference to be smaller (closer to physical simultaneity) for the VGPs than for the NVGPs, but this did not reach significance (VGP, $M = 120.00$ msec; NVGP, $M = 140.84$ msec) [$t(34) = 1.24$, $p = .22$].

Other assessments of accuracy on the temporal-order judgment task. Our initial hypotheses had been that the VGPs would be better than the NVGPs at those specific SOAs at which the task was particularly difficult (i.e., at those SOAs close to physical simultaneity). To determine whether this was indeed the case, we calculated the overall accuracy from −50 to +50 msec for each participant. Comparing the data between groups revealed that at these specific SOAs, the VGPs were indeed more accurate than the NVGPs (VGP, $M = 61.30\%$ correct; NVGP, $M = 53.66\%$ correct) [$t(34) = 2.72$, $p = .01$]. Furthermore, the NVGPs were biased toward reporting that the visual stimulus came first at the SOA of 0 msec; their average response significantly differed from chance [$t(17) = 2.40$, $p = .03$], whereas the VGPs' responses did not [$t(17) = 1.00$, $p = .33$].

The simultaneity judgment task revealed that the VGPs differed from the NVGPs when the visual stimulus came before the auditory at the larger SOAs. To examine possible similar effects here, we collapsed the proportion of *auditory first* responses across SOAs from +200 to +300 msec and from −200 to −300 msec. Doing this revealed that when the auditory stimulus came before the visual (i.e., from −300 to −200 msec), the VPGs did not differ from the NVGPs in their judgments [$t(34) = 0.616$, $p = .54$]; however, when the auditory stimulus came after the visual (i.e., from +200 to +300 msec), the VGPs and the NVGPs did differ on their judgments, with the VGPs being more likely to accurately report that the auditory stimulus came second [$t(34) = 2.012$, $p = .05$].

Correlation Between VGP Status and Temporal Processing

Our continuous measure of video game experience calculated from the postexperiment questionnaire provides an additional means to assess the relationship between video game experience and the temporal processing of multisensory stimuli. To do so, we examined correlations between the participants' amount of video game experience and their point of subjective simultaneity in the simultaneity judgment task. For this analysis, all of the participants ($n = 45$) were included so that the amount of video game experience value was continuous, rather than just at the extremes (i.e., we included the participants who were not classified as either VGPs or NVGPs). Our video game questionnaire score was directly related to the amount of experience that a participant had had with playing video games, such that a higher score equated to more experience (see the Method section). The analysis indicated that the video game score significantly correlated with the point of subjective simultaneity ($r = -.39$, $p = .008$), with a higher video game score correlating with a shift of the point of subjectivity toward an auditory-first bias (Figure 3A). The participants with more video game experience were more likely to perceive auditory stimuli that preceded visual stimuli as occurring simultaneously.

As well, the standard deviation from the simultaneity judgment task (i.e., how great the spread was after the data had been fitted to a Gaussian distribution) correlated with the amount of gaming experience ($r = -.34$, $p = .02$), showing that the participants with more gaming experi-

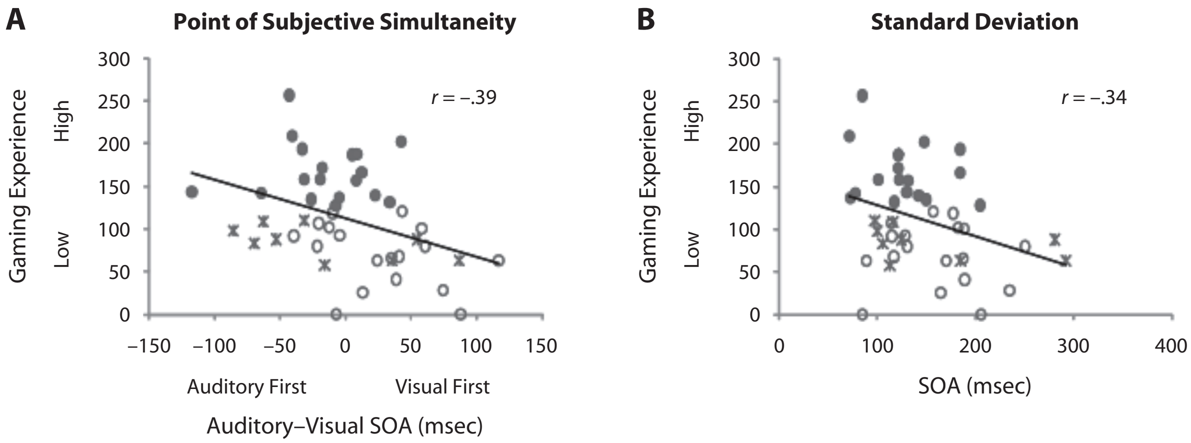

Figure 3. VGP experience correlates with judgment. Correlations between the amount of video game experience (score on our video game experience questionnaire, with a higher score signifying more experience), point of subjective simultaneity (A), and the standard deviation (B) for the simultaneity judgment task across VGPs ($n = 18$; closed circles), NVGPs ($n = 18$, open circles), and participants whose gaming experience fell between these two categories ($n = 9$; Xs). (A) As experience with video games increased, the point at which the participants were likely to report the stimuli as appearing simultaneously shifted toward the SOAs at which the auditory stimulus came before the visual stimulus. The confidence interval for the slope is −.57 to −.09. (B) As experience with video games increased, the participants had a smaller standard deviation (i.e., they were more likely to correctly identify the stimuli as not occurring simultaneously). The confidence interval for the slope is −.59 to −.05.

ence had a smaller standard deviation (Figure 3B). The participants with increased gaming experience were accordingly more likely to correctly assess stimuli that were separated in time as occurring at different times than those participants with little gaming experience.

DISCUSSION

Summary

In the present study, we had two main goals. First, we sought to examine whether there were individual differences present in the temporal perception of auditory and visual information that were modulated by action video game experience. Second, we sought to determine whether the visual benefits previously observed as the result of video game playing would translate to other modalities. Using two perceptual tasks (a simultaneity judgment task and a temporal-order judgment task), we found evidence that VGPs were able to distinguish auditory and visual stimuli as being temporally distinct at closer temporal intervals than were NVGPs.

Simultaneity judgment task summary. Simultaneity judgment tasks are generally considered good indicators of determining when stimuli that are *physically* separated in time become *perceptually* separated. Effects are best observed at the larger SOAs, where temporal distinctness is more apparent (e.g., Schneider & Bavelier, 2003; Zampini, Guest, et al., 2005). In the present experiment, VGPs were generally more accurate at discriminating the nonsimultaneity of the auditory and visual stimuli at smaller intervals than were NVGPs. The VGPs had a point of subjective simultaneity that did not differ from physical simultaneity (0 msec), whereas the NVGPs had a point of subjective simultaneity that was shifted toward conditions in which the visual stimulus preceded the auditory stimulus, significantly differing from physical simultaneity.

Notably, significant differences between the VGPs and the NVGPs arose primarily when the visual stimulus preceded the auditory stimulus. One possible explanation for this is that the VGPs may have heightened sustained visual attention (e.g., Green & Bavelier, 2006a), allowing them to focus their attention to the spatial position of the visual stimulus more quickly and accurately, which in turn allows them to determine that the subsequent auditory input did not occur simultaneously with the visual input. However, since the central and lateral conditions did not differ or interact with gamer status, it seems unlikely that this explanation alone could account for the observed differences. Another possibility that is consistent with our data is that the VGPs may be able to more rapidly process visual stimuli (e.g., Green & Bavelier, 2003), thereby allowing them to more quickly have attentional and perceptual resources available to distinguish the subsequent auditory input from the visual, rather than needing to devote continued resources toward processing the visual. Action video games require the rapid processing of vast amounts of visual information, and it is highly possible that extensive experience with these games would lead to more efficient visual processing.

Temporal-order judgment task summary. The temporal-order judgment task revealed that the VGPs were generally better than the NVGPs at being able to distinguish which stimulus came first, showing a more ideal behavioral pattern around SOAs close to physical simultaneity. Here too, the VGPs were better than the NVGPs when the auditory stimulus came after the visual, showing more accurate judgments at the largest positive SOAs (+200 to +300 msec). Interestingly, the NVGPs had a bias toward reporting the visual stimulus coming first at the SOA of 0 msec, whereas the VGPs were at chance at this SOA, showing more precision in their judgments. This bias for the NVGPs to report the visual stimulus first could be the result of a form of attentional capture. Although it has been shown that NVPGs are less able to spread their attention throughout space or time in within-modality tasks (Green & Bavalier, 2003, 2006a), it is equally possible that they are unable to spread their attention across modalities as well. The result of this possibility could be that their attention is pulled, or captured, by the most salient stimulus, which in this case may be the visual stimulus, since it has more features in its pattern than does the simple auditory tone. If their attention were pulled toward this visual stimulus, the NVGPs might be more likely to judge it as occurring first, since it was the first to capture their attention.

Task differences and biases. Simultaneity judgment and temporal order judgment tasks are thought to tap into somewhat different underlying mechanisms (van Eijk et al., 2008). This may explain some of the subtle differences revealed in the present study. For example, when the visual stimulus preceded the auditory stimulus, the VGPs revealed robust differences in the simultaneity judgment task relative to the NVGPs, with smaller, but still significant, differences in the temporal-order judgment task. Another potential difference between these two tasks that may introduce a bias into the simultaneity judgment task is the nature of the response requirement. Given that there was an equal probability in the two tasks of one stimulus coming before the other (i.e., auditory or visual first), in the temporal-order judgment task, responses of *auditory first* or *visual first* would be equally likely to occur. In the simultaneity judgment task, however, only 1 out of 13 SOAs was physically simultaneous (0 msec SOA), and thus, one could argue that this task creates an artificial bias toward responding *nonsimultaneous*. Importantly, however, auditory and visual information separated by SOAs ranging from approximately $+150$ to -150 msec are typically reported as occurring simultaneously (e.g., Zampini, Guest, et al., 2005), thus resulting in a much more balanced distribution of *perceptually* simultaneous and asynchronous trials, relative to the actual physical distribution. In addition, single-unit recording in the superior colliculus in animals has indicated that stimuli occurring within this temporal window of $+150$ to -150 msec are integrated into a single representation (e.g., Meredith et al., 1987). Therefore, although the absolute physical stimuli presented may be biased toward nonsimultaneity, the behavioral and neural responses suggest a more even balance.

Possible Mechanisms Underlying VGPs' Benefits

Although much of our discussion has been focused on attention, prior research suggests that the performance differences between VGPs and NVGPs may be due to other underlying elements. Much of the present evidence for the VGPs' benefits suggests that action video game playing alters both attentional and perceptual abilities (e.g., Green & Bavelier, 2003, 2007; Li et al., 2009). For example, VGPs (and NVGPs exposed to a video game training regimen) reveal enhanced visual acuity (Green & Bavelier, 2007) and contrast sensitivity (Li et al., 2009). Likewise, it has been suggested that VGPs and NVGPs may employ similar cognitive strategies but that VGPs do so with an added benefit of enhanced response-mapping abilities (Castel et al., 2005).

Beyond such visual and attentional benefits, there have also been discussions of motivational or strategic benefits that can arise from extensive video game playing (e.g., Fleck & Mitroff, 2008; see also Green & Bavelier, 2006b). It is certainly possible that the differences between VGPs and NVGPs in these and other tasks were the result of more global strategic differences, rather than, or perhaps in addition to, differences in attentional and perceptual abilities. Because this task was done on a computer, the VGPs may have been more motivated to perform well, since many games use a computer (or similar) interface, and the VGPs may have been more in their element. However, if increased motivation to perform well were underlying the VGPs' improved performance here, we should expect to see uniform improvements for the VGPs over the NVGPs. That is, regardless of whether the auditory stimulus preceded the visual or followed it, VGPs should differ from (i.e., be better than) NVGPs. However, our effects revealed a clear asymmetry in the simultaneity judgment task, as well as weaker but corroborating effects in the temporal-order judgment task, wherein the VGPs showed significant improvements only when the auditory stimulus followed the visual. Thus, although more work needs to be done to fully determine motivational differences between VGPs and NVGPs, it seems unlikely that the presently observed effects were due to differences in motivation alone.

Causal Effect of Video Game Playing?

An important question concerns whether the multisensory benefits observed here were caused by extensive action video game play, or whether people with a priori enhanced abilities were just more likely to have engaged in action video game play in their lives. In previous studies, NVGPs have been trained with video games (i.e., they played action video games for 10–50 h over the course of a training regimen), and it has been found that they subsequently reveal effects typical of VGPs (e.g., De Lisi & Wolford, 2002; Dorval & Pépin, 1986; Green & Bavelier, 2003, 2006b, 2007; Okagaki & Frensch, 1994). On the other hand, some other studies have not revealed such training benefits (e.g., Boot et al., 2008; Gagnon, 1985; Rosenberg et al., 2005; Sims & Mayer, 2002).

Although a training component was not included in the present study, the data acquired here—in particular, the asymmetry of the effects—can provide some insight on this issue. More specifically, the amount of our participants' video game playing experience correlated with their point of subjective simultanteity and the associated standard deviation (see the Results section and Figures 3A and 3B). In the simultaneity judgment task, the participants with more video game experience were more likely to perceive the stimuli as occurring simultaneously when the visual stimulus followed the auditory, whereas the participants with less experience were more likely to perceive the stimuli as occurring simultaneously when the visual stimulus preceded the auditory. Thus, although we cannot infer causation from this correlation, this observed relationship between the amount of experience and subjective perception, together with the previous training studies, suggests that extensive video game experience may in fact lead to altered multisensory perception.

Conclusions

In a world where humans are constantly facing a rapid barrage of stimuli from multiple modalities, it is of fundamental importance to be able to accurately integrate corresponding information and to parse noncorresponding information. We found that participants with extensive action video game experience are better able to distinguish events that occur close together in time, revealing enhanced multisensory perception and integration. These findings shed new light on individual differences in temporal aspects of multisensory integration and add to the growing body of evidence that suggests the importance of individual experience on perception.

AUTHOR NOTE

For helpful conversation, we thank the other members of the Mitroff and Woldorff labs. We also thank Melissa Bulkin and Ricky Green for assistance with data collection and Kenneth Roberts for technical assistance. We also thank Jeremy Wolfe and three anonymous reviewers for their helpful suggestions. This research was supported by NIMH Grant R03-MH080849 awarded to S.R.M., NINDS Grant R01-NS051048 awarded to M.G.W., and an NSF Graduate Research Fellowship awarded to S.E.D. Correspondence concerning this article should be addressed to S. E. Donohue, Center for Cognitive Neuroscience, Duke University, Box 90999, Durham, NC 27708-0999 (e-mail: sarah.donohue@duke.edu).

REFERENCES

Boot, W. R., Kramer, A. F., Simons, D. J., Fabiani, M., & Gratton, G. (2008). The effects of video game playing on attention, memory, and executive control. *Acta Psychologica*, **129**, 387-398.

Carriere, B. N., Royal, D. W., Perrault, T. J., Morrison, S. P., Vaughan, J. W., Stein, B. E., & Wallace, M. T. (2007). Visual deprivation alters the development of cortical multisensory integration. *Journal of Neurophysiology*, **98**, 2858-2867. doi:10.1152/jn.00587.2007

Castel, A. D., Pratt, J., & Drummond, E. (2005). The effects of action video game experience on the time course of inhibition of return and the efficiency of visual search. *Acta Psychologica*, **119**, 217-230. doi:10.1016/j.actpsy.2005.02.004

Coren, S., Ward, L. M., & Enns, J. T. (2004). *Sensation and perception* (6th ed.). Hoboken, NJ: Wiley.

De Lisi, R., & Cammarano, D. M. (1996). Computer experience and gender differences in undergraduate mental rotation performance. *Computers in Human Behavior*, **12**, 351-361.

De Lisi, R., & Wolford, J. L. (2002). Improving children's mental rotation accuracy with computer game playing. *Journal of Genetic Psychology*, **163**, 272-282.

Dorval, M., & Pépin, M. (1986). Effect of playing a video game on a measure of spatial visualization. *Perceptual & Motor Skills*, **62**, 159-162.

Driver, J., & Noesselt, T. (2008). Multisensory interplay reveals crossmodal influences on "sensory-specific" brain regions, neural responses, and judgments. *Neuron*, **57**, 11-23.

Feng, J., Spence, I., & Pratt, J. (2007). Playing an action video game reduces gender differences in spatial cognition. *Psychological Science*, **18**, 850-855. doi:10.1111/j.1467-9280.2007.01990.x

Fleck, M., & Mitroff, S. R. (2008). Videogamers excel at finding rare targets [Abstract]. *Journal of Vision*, **8**(6), 313a. doi:10.1167/8.6.313.

Gagnon, D. (1985). Videogames and spatial skills: An exploratory study. *Educational Communication & Technology Journal*, **33**, 263-275.

Ghoshal, A., Pouget, P., Popescu, M., & Ebner, F. (2009). Early bilateral sensory deprivation blocks the development of coincident discharge in rat barrel cortex. *Journal of Neuroscience*, **29**, 2384-2392. doi:10.1523/JNEUROSCI.4427-08.2009

Green, C. S., & Bavelier, D. (2003). Action video game modifies visual selective attention. *Nature*, **423**, 534-537. doi:10.1038/nature01647

Green, C. S., & Bavelier, D. (2006a). Effect of action video games on the spatial distribution of visuospatial attention. *Journal of Experimental Psychology: Human Perception & Performance*, **32**, 1465-1478. doi:10.1037/0096-1523.32.6.1465

Green, C. S., & Bavelier, D. (2006b). Enumeration versus multiple object tracking: The case of action video game players. *Cognition*, **101**, 217-245. doi:10.1016/j.cognition.2005.10.004

Green, C. S., & Bavelier, D. (2007). Action-video-game experience alters the spatial resolution of vision. *Psychological Science*, **18**, 88-94. doi:10.1111/j.1467-9280.2007.01853.x

Greenfield, P. M., DeWinstanley, P., Kilpatrick, H., & Kaye, D. (1994). Action video games and informal education: Effects on strategies for dividing visual attention. *Journal of Applied Developmental Psychology*, **15**, 105-123. doi:10.1016/0193-3973(94)90008-6

Griffith, J. L., Voloschin, P., Gibb, G. D., & Bailey, J. R. (1983). Differences in eye–hand motor coordination of video-game users and nonusers. *Perceptual & Motor Skills*, **57**, 155-158.

Harrar, V., & Harris, L. R. (2008). The effect of exposure to asynchronous audio, visual, and tactile stimulus combinations on the perception of simultaneity. *Experimental Brain Research*, **186**, 517-524. doi:10.1007/s00221-007-1253-0

Li, R., Polat, U., Makous, W., & Bavelier, D. (2009). Enhancing the contrast sensitivity function through action video game training. *Nature Neuroscience*, **12**, 549-551.

Liotti, M., Ryder, K., & Woldorff, M. G. (1998). Auditory attention in the congenitally blind: Where, when and what gets reorganized? *NeuroReport*, **9**, 1007-1012. doi:10.1097/00001756-199804200-00010

McClurg, P. A., & Chaille, C. (1987). Computer games: Environments for developing spatial cognition? *Journal of Educational Computing Research*, **3**, 95-111.

Meredith, M. A., Nemitz, J. W., & Stein, B. E. (1987). Determinants of multisensory integration in superior colliculus neurons: I. Temporal factors. *Journal of Neuroscience*, **7**, 3215-3229.

Okagaki, L., & Frensch, P. A. (1994). Effects of video game playing on measures of spatial performance: Gender effects in late adolescence. *Journal of Applied Developmental Psychology*, **15**, 33-58.

Poliakoff, E., Shore, D. I., Lowe, C., & Spence, C. (2006). Visuotactile temporal order judgments in ageing. *Neuroscience Letters*, **396**, 207-211.

Putzar, L., Goerendt, I., Lange, K., Rösler, F., & Röder, B. (2007). Early visual deprivation impairs multisensory interactions in humans. *Nature Neuroscience*, **10**, 1243-1245. doi:10.1038/nn1978

Quaiser-Pohl, C., Geiser, C., & Lehmann, W. (2006). The relationship between computer-game preference, gender, and mental-rotation ability. *Personality & Individual Differences*, **40**, 609-619. doi:10.1016/j.paid.2005.07.015

Recanzone, G. H., Schreiner, C. E., & Merzenich, M. M. (1993). Plasticity in the frequency representation of primary auditory cortex following discrimination training in adult owl monkeys. *Journal of Neuroscience*, **13**, 87-103.

Rosenberg, B. H., Landsittel, D., & Averch, T. D. (2005). Can video games be used to predict or improve laparoscopic skills? *Journal of Endourology*, **19**, 372-376.

Schneider, K. A., & Bavelier, D. (2003). Components of visual prior entry. *Cognitive Psychology*, **47**, 333-366. doi:10.1016/S0010-0285(03)00035-5

Sims, V. K., & Mayer, R. E. (2002). Domain specificity of spatial expertise: The case of video game players. *Applied Cognitive Psychology*, **16**, 97-115. doi:10.1002/acp.759

Spence, C., Shore, D. I., & Klein, R. M. (2001). Multisensory prior entry. *Journal of Experimental Psychology: General*, **130**, 799-832. doi:10.1037/0096-3445.130.4.799

STEIN, B. E., & MEREDITH, M. A. (1993). *The merging of the senses*. Cambridge, MA: MIT Press.

STEIN, B. E., & STANFORD, T. R. (2008). Multisensory integration: Current issues from the perspective of the single neuron. *Nature Reviews Neuroscience*, **9**, 255-266.

STONE, J. V., HUNKIN, N. M., PORRILL, J., WOOD, R., KEELER, V., BEANLAND, M., ET AL. (2001). When is now? Perception of simultaneity. *Proceedings of the Royal Society B*, **268**, 31-38.

VAN EIJK, R. L. J., KOHLRAUSCH, A., JUOLA, J. F., & VAN DE PAR, S. (2008). Audiovisual synchrony and temporal order judgments: Effects of experimental method and stimulus type. *Perception & Psychophysics*, **70**, 955-968. doi:10.1037/0096-3445.130.4.799

VAN WASSENHOVE, V., GRANT, K. W., & POEPPEL, D. (2007). Temporal window of integration in auditory–visual speech perception. *Neuropsychologia*, **45**, 598-607. doi:10.1016/j.neuropsychologia.2006.01.001

VATAKIS, A., BAYLISS, L., ZAMPINI, M., & SPENCE, C. (2007). The influence of synchronous audiovisual distractors on audiovisual temporal order judgments. *Perception & Psychophysics*, **69**, 298-309.

VATAKIS, A., NAVARRA, J., SOTO-FARACO, S., & SPENCE, C. (2007). Temporal recalibration during asynchronous audiovisual speech perception. *Experimental Brain Research*, **181**, 173-181.

VATAKIS, A., & SPENCE, C. (2006). Temporal order judgments for audiovisual targets embedded in unimodal and bimodal distractor streams. *Neuroscience Letters*, **408**, 5-9.

VROOMEN, J., KEETELS, M., DE GELDER, B., & BERTELSON, P. (2004). Recalibration of temporal order perception by exposure to audio–visual asynchrony. *Cognitive Brain Research*, **22**, 32-35. doi:10.1016/j.cogbrainres.2004.07.003

WEST, G. L., STEVENS, S. S., PUN, C., & PRATT, J. (2008). Visuospatial experience modulates attentional capture: Evidence from action video game players. *Journal of Vision*, **8**(16, Art. 13), 1-9.

ZAMPINI, M., BROWN, T., SHORE, D. I., MARAVITA, A., RÖDER, B., & SPENCE, C. (2005). Audiotactile temporal order judgments. *Acta Psychologica*, **118**, 277-291. doi:10.1016/j.actpsy.2004.10.017

ZAMPINI, M., GUEST, S., SHORE, D. I., & SPENCE, C. (2005). Audio–visual simultaneity judgments. *Perception & Psychophysics*, **67**, 531-544.

ZAMPINI, M., SHORE, D. I., & SPENCE, C. (2003). Audiovisual temporal order judgments. *Experimental Brain Research*, **152**, 198-210.

ZAMPINI, M., SHORE, D. I., & SPENCE, C. (2005). Audiovisual prior entry. *Neuroscience Letters*, **381**, 217-222.

(Manuscript received June 8, 2009;
revision accepted for publication December 22, 2009.)