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Enhanced Implicit Sequence Learning in College-age Video Game Players and Musicians

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SUMMARY: We examined whether college-age video game players and musicians are better than controls at implicit sequence learning in the Alternating Serial Reaction Time Task. People learn to use subtle sequence regularities to respond more accurately and quickly to predictable versus non-predictable events. Although previous studies have shown experts' enhanced processing speed and perception, this is the first to demonstrate that people who regularly play video games or a musical instrument showed greater implicit sequence learning, suggesting that experience playing games or music may improve the efficiency with which people learn sequential regularities in the environment. Copyright © 2011 John Wiley & Sons, Ltd.

Experience with playing video games or a musical instrument influences not only domain-specific skills but also more general cognitive processes such as visual perception, attention, memory, multi-sensory processing and processing speed (Boot, Kramer, Simons, Fabiani & Gratton, 2008; Brochard, Dufour & Despres, 2004; Donohue, Woldorff & Mitroff, 2010; Dye, Green & Bavelier, 2009a; Green & Bavelier, 2006; Rauscher, Shaw, Levine, Wright, Dennis & Newcomb, 1997; Schellenberg, 2004). However, no studies to date have examined how experience with video games or music is related to the ability to implicitly learn sequential environmental regularities, such as those that underlie language and procedural skills. The present study is the first to investigate whether experience with playing video games or a musical instrument enables people to be more sensitive to subtle regularities in their environment.

Implicit learning can be examined by exposing people to subtle regularities (Reber, 1993) and is said to occur if individuals improve in the speed and/or accuracy of their responses to predictable events and yet are unable to describe such regularities. In this study, we use the Alternating Serial Reaction Time Task (ASRTT, Howard & Howard, 1997; Howard, Howard, Japiske, DiYanni, Thompson & Somberg, 2004), in which people make key presses to each of a series of targets appearing at different locations on a computer screen. In the ASRTT, a four-element repeating sequence of pattern events alternates with randomly determined ones, such that some sequences of three events (high-frequency triplets) occur more often than others (low-frequency triplets) (Howard & Howard, 1997). Participants are not informed of any pattern, and sequence learning is measured by the difference in performance (reaction time and accuracy) between the last event in high-frequency versus low-frequency triplets. Because people fail to show explicit knowledge of the regularity even on sensitive recognition tasks, the ASRTT permits us to examine how people learn sequential regularities implicitly—without intent or explicit awareness of what they have learned.

For both video game players and musicians, learning and responding to sequential events are important components of skill in their respective domains. If extended practice with sequences facilitates picking up new sequential regularities, then both video game players and musicians should show more implicit learning on the ASRTT than controls.

METHOD

Participants

Participants were recruited through an undergraduate participant pool at The Catholic University of America. Each person read and signed an informed consent, approved by the University's Institutional Review Board, which explained the study's procedures.

Eighteen video game players (17 male, 1 female), 18 musicians (3 male, 15 female) and 28 controls (13 male, 15 female) participated. Following Green and Bavelier (2003), video game players (henceforth referred to as 'gamers') played 4 hours or more a week ($M = 10$ hours; range: 4–20 hours) of 'quick-thinking' video games, such as racing, sports or action games. Musicians had 6 years or more ($M = 10$ years; range: 6–16 years) of formal training on any instrument, and part of that training had taken place in the last 5 years. They had played for 10 or more hours in the last month, were able to read sheet music and, on average, they played for 6.8 hours a week (range: 2–17 hours). Control participants had much less experience playing video games ($M = 0.62$ hours a week, range: 0–4) and music ($M = 0.66$ years of experience, range: 0–9).

As shown in Table 1, the groups did not differ in their mean age, years of education, self-rated health or in standardized tests of visual motor speed and coordination

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Table 1. Participant mean (and ranges) characteristics

	Group		
	Musicians	Gamers	Controls
Sex			
Female	15	1	15
Male	3	17	13
Age (years)[a]	19.43 (18–22)	19.65 (18–24)	19.15 (17–22)
Education (years)[a]	12.66 (12–15)	12.61 (12–14)	12.86 (12–15)
Self-rated health[a,b]	4.28 (3–5)	4.50 (3–5)	4.39 (3–5)
WAIS-III[c] Digit–Symbol Coding[a]	86.06 (47–111)	78.81 (67–98)	82.39 (46–104)
WAIS-III Digit Span test[a]	17.50 (13–23)	19.11 (11–26)	16.46 (10–28)
WMS-III[d] Spatial Span test[a]	16.72 (11–28)	17.83 (11–30)	16.46 (11–21)
WAIS-III Vocabulary test[a]	35.44 (26–50)	32.67 (20–46)	34.11 (17–81)

[a]No significant group differences.
[b]Self-rated health responses ranged from 1 (*poor*) to 5 (*excellent*).
[c]WAIS-III, Wechsler Adult Intelligence Scale, 3rd Edition.
[d]WMS-III, Wechsler Memory Scale, 3rd Edition.

(Wechsler Adult Intelligent Scale, 3rd edition, WAIS-III, Digit–Symbol Coding), attention and memory (WAIS-III Digit Span), visuospatial working memory (Wechsler Memory Scale, 3rd edition, WMS-III, Spatial Span) or verbal ability (WAIS-III Vocabulary).

Procedure

Stimuli, apparatus and data reduction

The ASRTT was performed on an iMac computer with a 38-cm monitor. The stimuli, apparatus and procedure were similar to those used previously (e.g. Howard & Howard, 1997). Participants were instructed to place their middle and index fingers of each hand on the keys marked ‘z’, ‘x’, ‘.’, and ‘/’, respectively. The keys corresponded to four equally spaced circles on the computer screen. See Figure 1 for a graphical representation of the task. On each trial, one circle became black and remained so until the participant pressed the key corresponding to this target. After a delay of 120 milliseconds, the next target appeared. Participants completed eight epochs of five blocks. Each block consisted of 10 random trials followed by 80 learning trials. These 80 trials consisted of 10 repetitions of an eight-element sequence, in which random trials alternated with pattern trials (e.g. 1r2r3r4r where 1–4 refer to the spatial position, left to right, and r refers to a randomly selected position). Participants took a brief break after each block and a longer break halfway through the session, between epochs 4 and 5.

The data from the first 10 random trials of each block were not analyzed. For the remaining 80 trials, each person’s sequence was parsed into a series of overlapping triplets using a sliding three-trial window. Because pattern and random events alternate, some successive runs of three events, or triplets, occur more often than others. For example, for the sequence 1r2r3r4r, the triplets 132 and 431 occur often, whereas the triplets 231 and 134 occur rarely, ending only on random trials. We refer to the former as high-frequency and the latter as low-frequency *triplets* and the third event of each as high-frequency and low-frequency *trials*, respectively. Previous studies have shown that people learn triplet frequencies implicitly, responding more quickly and accurately to the third trial of high-frequency than low-frequency triplets with practice despite the fact that they do not become aware of the alternating nature of the sequence (Howard et al., 2004).

Two kinds of low-frequency triplets, repetitions and trills, were excluded from analyses since people reveal pre-existing response tendencies to these triplets (Howard et al., 2004; Soetens, Melis & Notebaert, 2004). Repetitions are those triplets that repeat a single element (111, 222, 333 and 444), and trills are those that begin and end with the same element, with a different element in the middle (e.g. 121, 343, 414). In

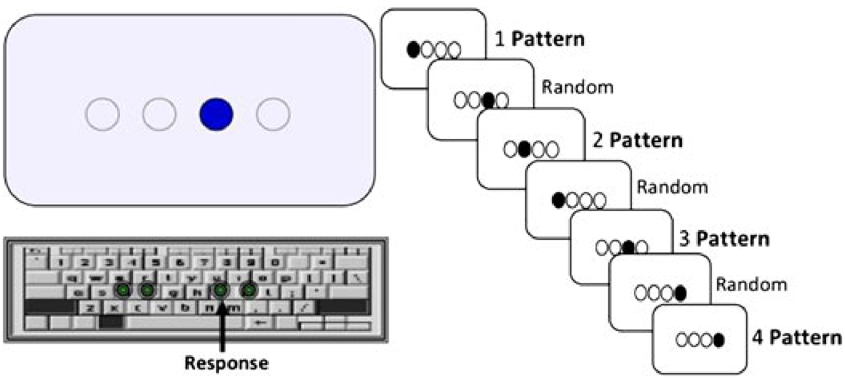

Figure 1. Graphical representation of the ASRTT where the pattern is 1r2r3r4r

general, from the outset, people responded exceptionally fast to repetitions and exceptionally slowly to trills. These initial response tendencies did not occur for other triplets.

Triplets that ended on pattern trials were always high frequency, and 25% of those that ended on random trials were high frequency by chance; thus, the 16 different high-frequency triplets made up 62.5% of the total triplets. The 32 low-frequency triplets (excluding the four repetitions and 12 trills described above) occurred 25% of the time. As a result, each high-frequency triplet occurred five times more often than each low-frequency triplet (i.e. 62.5/16 vs 25/32).

Six patterns were counterbalanced across participants (1r2r3r4r, 1r2r4r3r, 1r3r2r4r, 1r3r4r2r, 1r4r2r3r and 1r4r3r2r). Since the repeating pattern forms a continuous sequence, these six patterns include all permutations of the four alternating events. The computer was programmed to guide participants to an accuracy level of about 92% via an end-of-block visual display. If accuracy for a block was above 93%, the computer displayed 'focus more on speed', and if accuracy was below 91%, the computer displayed 'focus more on accuracy'.

Upon completion, participants were asked questions designed to probe for declarative knowledge, as in previous studies with this task (e.g. Howard et al., 2004). The experimenter read the following questions aloud one at a time and recorded participants' responses: (1) 'Do you have anything to report regarding the task?' (2) 'Did you notice anything special about the task or the materials?' (3) 'Did you notice any regularity in the way the stimulus was moving on the screen?' If participants answered 'yes' to question 3, they were asked (4) 'Did you attempt to take advantage of any regularities you noticed in order to anticipate subsequent targets? If so, did this help?' (5) 'In fact, there was some regularity to the sequences you responded to. What do you think it was? That is, try to describe any regularity you think there might have been.'

To further examine declarative knowledge after learning, participants performed a card-sorting task in which they sorted 7.6 cm × 12.7 cm white index cards that displayed three rows of four circles. Each line represented the four circles seen on the screen throughout the experiment. One circle on each line was black, so that each card represented three successive trials (a triplet). Participants placed each of the 64 cards into one of two piles, labeled 'Frequent' and 'Rare', depending on how often they believed the triplet sequence had occurred during the task.

Participants also completed a computerized recognition task, in which they observed a sequence of circles turning black one at a time. They then rated the certainty of each sequence's occurrence during the learning trials using a four-point scale with 1 being 'certain the sequence did not occur' and 4 being 'certain the sequence did occur'. Participants performed 20 trials, each consisting of a 16-element sequence—two repetitions of an alternating eight-element pattern from a random starting point. Ten of these trials contained targets: pattern-consistent high-frequency sequences that occurred in the experiment; 10 contained foils: new sequences produced by reversing the sequence structure (low frequency).

RESULTS

Reaction time and accuracy analyses

Median reaction times (RTs) were determined separately for correct high-frequency and low-frequency triplets for each participant on each block. The median RTs were then averaged across blocks to obtain a mean of the median RT for each epoch. A similar procedure was used for accuracy.

In Figure 2, the mean of the median reaction time (upper graph) and mean proportion correct (lower graph) are plotted for all groups. The RT and accuracy data were subjected to separate 3 (Group) × 2 (Triplet type) × 8 (Epoch) mixed design analyses of variance (ANOVAs) with repeated measures on the Triplet type and Epoch factors to compare the performance of the gamers, the musicians and the controls for the two triplet types (high and low frequency) across epochs. As is typical, the groups got faster overall with practice, as seen in the significant main effect of Epoch for RT [F (7, 434) = 150.40, MSE = 79 227, $p < 0.0001$, $r_{\text{effect}} = 0.84$], revealing general skill learning. The main effect of Triplet Type [F (1, 62) = 134.27, MSE = 46 468, $p < 0.0001$, $r_{\text{effect}} = 0.83$] and the Triplet Type × Epoch interaction [F (7, 434) = 8.43, MSE = 634, $p < 0.0001$, $r_{\text{effect}} = 0.35$] are also significant for RT, revealing sequence-specific learning. Participants responded 13 milliseconds faster on high-frequency than low-frequency triplets overall (387 vs 400 milliseconds, respectively), and this difference was greater by the end of training on epoch 8 (18 milliseconds) than it was at the beginning on epoch 1 (5 milliseconds).

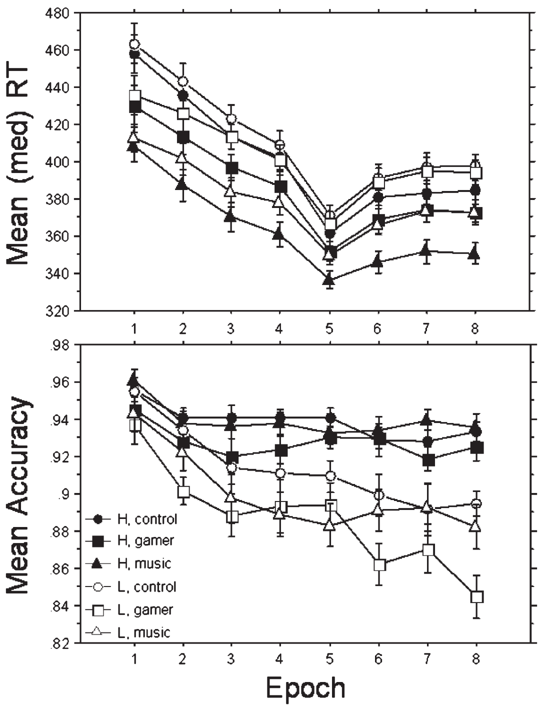

Figure 2. RTs for correct responses (upper panel) and accuracy (lower panel) as a function of epoch and triplet type (H, high frequency; L, low frequency) for the ASRTT. Each epoch consists of five blocks of 80 learning trials. Participants rested for a few minutes in between each epoch and took a longer break between epochs 4 and 5 (mid-way through the session)

For accuracy, there was a significant main effect of Epoch [F (7, 434) = 17.35, MSE = 0.03, $p < 0.0001$, $r_{effect} = 0.47$] and a significant main effect of Triplet Type [F (1, 62) = 208.89, MSE = 0.31, $p < 0.0001$, $r_{effect} = 0.88$]. The Triplet Type × Epoch interaction was significant [F (7, 434) = 12.272, MSE = 0.01, $p < 0.0001$, $r_{effect} = 0.41$], revealing sequence-specific learning. Participants were 3% more accurate on high-frequency than low-frequency trials overall (93% vs 90%, respectively), and this difference was greater by the end of training on epoch 8 (5%) than it was at the beginning on epoch 1 (.07%).

In addition, and more important for present purposes, there are two group differences. First, for RT, the main effect of Group is significant [F (2, 62) = 6.95, MSE = 16 033, $p < 0.01$, $r_{effect} = 0.43$]. A post hoc analysis confirmed that musicians were faster overall than controls (372 vs 407 milliseconds, respectively) [F (1, 45) = 13.43, MSE = 16 583, $p < 0.001$, $r_{effect} = 0.48$] and that musicians were also faster than gamers, $r_{effect} = 0.39$], but there was no difference between gamers and controls (395 vs 407 milliseconds, respectively) [F (1, 45) = 1.52, MSE = 18 149, $p = 0.22$]. The group difference occurs early and continues throughout the experiment demonstrating an advantage for musicians in responding to motor sequences compared to gamers and controls.

The second and novel group difference is that, as predicted, both gamers and musicians show greater learning of the sequential structure than the controls. The Group × Triplet Type interaction is significant for RT [F (2, 62) = 3.58, MSE = 1240, $p < 0.05$, $r_{effect} = 0.32$] and for accuracy [F (2, 62) = 5.14, MSE = 0.01, $p < 0.01$, $r_{effect} = 0.38$]. Post hoc ANOVAs of RT comparing groups revealed significantly greater sequence-specific learning for musicians than controls [F (1, 45) = 6.64, MSE = 1697, $p < 0.05$, $r_{effect} = 0.36$] and for gamers than controls [F (1, 45) = 4.21, MSE = 1732, $p < 0.05$, $r_{effect} = 0.29$] but no difference between gamers and musicians [F (1, 34) = 3.73, MSE = 0.14, $p = 0.98$]. Likewise, for accuracy, there was significantly greater learning for musicians than controls [F (1, 45) = 6.52, MSE = 0.01, $p < 0.05$, $r_{effect} = 0.36$] and for gamers than controls [F (1, 45) = 9.39, MSE = 0.01, $p < 0.01$, $r_{effect} = 0.42$] but no difference between gamers and musicians [F (1, 34) = 0.08, $p = 0.78$]. Thus, both the gamers and musicians were more sensitive to the sequence structure than controls on both the RT and accuracy measures. This group difference in sequence sensitivity can be more clearly seen in Figure 3, in which the triplet-type effects are shown (RT: upper graph; accuracy: lower graph). This figure makes clear that gamers and musicians reveal a greater high versus low triplet-type difference that emerges early and persists throughout the experiment.

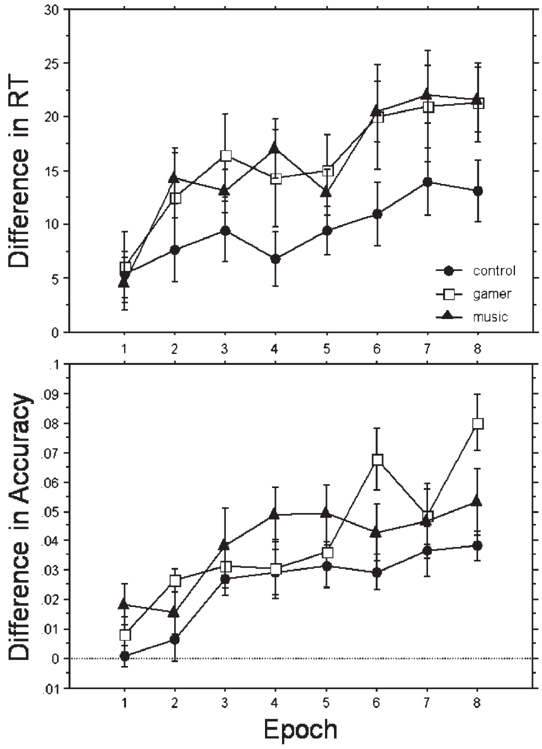

Figure 3. Difference in reaction time between low-frequency and high-frequency triplets (RT on low-frequency minus RT on high-frequency triplets—upper panel) and difference in accuracy between high-frequency and low-frequency trials (accuracy on high-frequency minus accuracy on low-frequency triplets—lower panel) across epochs for the ASRTT. In both cases, higher scores signal more sequence learning

Is learning declarative?

Responses on the post-experimental questions, the card-sorting task and the computerized recognition task provide consistent evidence that participants did not acquire declarative knowledge of the sequence structure. Questionnaire responses were similar for all groups and were consistent with data from previous ASRTT studies (e.g. Howard et al., 2004). When asked whether they noticed any regularity, 69% of the participants reported that they felt there was a pattern, but no one identified the alternating nature of the sequence or accurately described their regularity. In regards to strategy, the only difference among groups was that several musicians commented that they viewed the targets as musical notes. Three musicians stated that they associated a sound with each of the four positions, and they thought it helped them to respond more accurately.

For the card-sorting data, to determine if individuals were able to explicitly judge the relative frequency with which each triplet sequence occurred, a 3 × 2 ANOVA comparing the proportion of 'frequent' responses for gamers, musicians and controls for each triplet type (high and low frequency) revealed no significant effects ($M = .618$, $SE = .020$ and $M = .612$, $SE = .029$ for the low-frequency and high-frequency triplets, respectively), and there were no significant differences among musicians ($M = .644$, $SE = .024$), gamers ($M = .614$, $SE = .024$) and controls ($M = .587$, $SE = .025$). Thus, consistent with the questionnaire responses, the card-sorting data confirm that participants did not have explicit knowledge of the sequence structure they had learned.

For the computerized recognition task, a 3 × 2 ANOVA comparing the mean familiarity ratings for gamers, musicians and controls for each sequence type (target and foil) revealed no significant effects. Thus, there was no difference between the overall mean recognition rating for targets ($M = 2.65$, $SE = .083$) and foils ($M = 2.69$, $SE = .064$) and no difference among overall mean ratings for musicians ($M = 2.64$, $SE = .073$), gamers ($M = 2.69$, $SE = .080$) and controls ($M = 2.69$, $SE = .069$). Thus, consistent with the questionnaire responses and the card-sorting data, the computerized recognition data confirm that participants did not have explicit knowledge of the sequence structure they had learned.

DISCUSSION

The most important findings is that both gamers and musicians showed significantly greater implicit learning of sequential context than controls on the ASRTT. That is, the difference between high-frequency and low-frequency triplet types was greater for gamers and musicians than for controls, and this was the case for both speed and accuracy measures. This learning was implicit in all three groups, in that no group showed any evidence of explicit awareness of the regularity.

Previous findings have shown that experience with video games and music is associated with enhanced visual perception, attention, memory, multi-sensory processing and processing speed (Boot et al., 2008; Brochard et al., 2004; Donohue et al., 2010; Dye et al., 2009a; Green & Bavelier, 2006; Rauscher et al., 1997; Schellenberg, 2004). The present study is the first to demonstrate that extensive experience with music or video games is associated with enhanced implicit learning of sequential regularities in an environment that is unrelated to the skill-specific activity. Consistent with Schellenberg's (2004) finding that musical training leads to enhanced cognitive function, the present study suggests that extended experience with music and video games can enhance some types of learning. This is especially important as people consider ways to remain cognitively fit as they age, and this suggests that playing video games and music may be two ways to maintain implicit learning abilities.

We can rule out a number of less interesting explanations of why these differences occur. First, it is unlikely that we happened to sample gamers and musicians who were more able overall than controls since the three groups did not differ on any of the standardized neuropsychological tests we administered. Second, we can rule out differences in the ability of our gamers and musicians to develop explicit awareness of the underlying regularities in either task. No group revealed explicit knowledge on any of the three measures we used. Third, it appears that musicians and gamers do not have an overall advantage in perceptual-motor processing, since scores on a standardized test of visual motor speed (WAIS-III Digit–Symbol Coding) were not different among the groups [F (2, 60) = 1.20, $p = 0.31$]. Fourth, the group differences in learning cannot be due to the groups adopting different speed/accuracy tradeoffs because there were no group differences in overall accuracy. Fifth, while there is a gender imbalance across the groups, with the gamers being predominantly male, as is typical (e.g. Padilla-Walker, Nelson, Carroll & Jensen, 2010), and the musicians being predominantly female, an analysis of the gender-balanced control group revealed that, although men were faster than women [F (1, 27) = 8.77, MSE = 15 904, $p < 0.01$, $r_{effect} = 0.34$], there was no difference in learning. In addition, despite the gender difference between the musicians and gamers, the two groups showed equivalent learning on both tasks. Although previous work has reported mixed findings for gender effects in RT tasks (e.g. Mezzacappa, 2004; Dye, Green & Bavelier, 2009b; Burton et al., 2004), gender cannot explain the learning differences we observed.

Thus, our findings suggest that both gamers and musicians are better than controls at implicit learning of subtle sequential structure. It is possible that the faster overall responding of musicians underlies their greater sensitivity to the sequence structure on the ASRTT. That is, faster responding would reduce the inter-stimulus interval and facilitate the perceptual grouping of non-adjacent events (Frensch & Miner, 1994). This is unlikely, however, because the gamers showed as much sequence learning as the musicians, even though the gamers were no faster overall than the controls. In addition, we examined if learning scores on the ASRTT were correlated with reaction time across all participants for both the accuracy and RT measures and found that they were not.

The differences in implicit sequence learning may reflect the fact that both gamers and musicians develop skills in motor and perceptual learning and in processing sequential events that lead to greater learning of sequential relationships (cf. Nemeth, Hallgato, Janacsek, Sandor & Londe, 2009). This suggests that as both gamers and musicians practice their skills, they not only learn new sequential relationships within their respective domains, but they also improve in their more general ability to learn new sequential relationships implicitly. That is, through practicing in their domains, they become more sensitive to sequential regularities in general.

Of course, the correlational nature of our data means that we cannot determine the direction of cause. It is possible that rather than music/gaming practice increasing implicit learning ability, it is that people who are good at implicit sequence learning are more likely to become musicians and gamers. Future training studies will be needed to distinguish between these possibilities.

In summary, we have demonstrated enhanced implicit learning of sequential regularities for experienced gamers and musicians. Although previous studies have shown enhanced attention, motor and perceptual skills in gamers and musicians, this is the first demonstration that extensive experience with video games or music is related to improved efficiency in implicit learning of sequential regularities. While causality can only be demonstrated with training studies (Boot et al., 2008; Green & Bavelier, 2003, 2006), our findings suggest that there might be widespread effects of this experience beyond the specificity of the practiced activity.

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