

Age of Acquisition in Sport: Starting Early Matters

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Although the age at which a skill is learned (age of acquisition [AoA]) is one of the most studied predictors of success in domains ranging from language to music, very little work has focused on this factor in sports. In order to uncover how the age at which a skill is learned relates to how athletes cognitively represent that skill, we asked a group of skilled golfers who learned to play golf before (early learners) or after (late learners) the age of 10 to take a series of putts on an indoor putting green. Golfers putted in isolation (single-task condition), while monitoring a stream of words presented over a loudspeaker (dual-task condition), or while being instructed to attend to specific aspects of their golf swing (skill-focused condition). Early and late learners putted equally well in the single-task and dual-task conditions. However, in the skill-focused condition, golfers who learned earlier performed worse than those who learned later. The results are consistent with the notion that AoA influences the manner in which sports, like other domains such as language and music, are represented in memory.

Tiger Woods, one of the most dominant players in golf, has two advantages over other players: the age he started playing (age 2) and the amount of time he has practiced. Although researchers have investigated the role of practice in facilitating sports expertise (see Starkes & Allard, 1993), little is known about how the age of initial learning (or age of acquisition [AoA]) affects athletic performance. Here we provide the first demonstration that early learners of golf differ from late learners in terms of the memory processes sup-

porting the execution of a putting task, even when both groups are matched on golf skill. These differences may carry implications for achieving high levels of success in sport and especially for performance in high-stakes competition.

Theories of Skill Acquisition

Theories of skill acquisition and automaticity suggest that novel sensorimotor skill performance is based on explicitly retrievable declarative knowledge that is

held in working memory and consciously attended in real time (Anderson, 1983; Fitts & Posner, 1967; Proctor & Dutta, 1995). As learning progresses, large portions of this control structure are thought to become proceduralized or automated with extended practice, shifting the memory structures and reducing the attention demands of real-time skill execution. Proceduralization is especially likely for the mechanics involved in execution and also for lower-level planning and decision making that occur in commonly encountered situations and heavily practiced phases of task activity (Fitts & Posner, 1967; Keele, 1986; Kimble & Perlmutter, 1970; Proctor & Dutta, 1995).

Because step-by-step execution runs largely outside of conscious control at high levels of practice (Anderson, 1983; Fitts & Posner, 1967), performance is not harmed when a secondary attention-demanding task (e.g., word shadowing) is added to primary skill execution (e.g., soccer dribbling or baseball batting; Beilock, Carr, MacMahon, & Starkes, 2002; Gray, 2004). However, highly skilled performance is hurt when implicit skill processes are brought into conscious awareness. For example, expert soccer players show a decrement in performance when attending to the side of the foot that just touched the ball while dribbling a soccer ball (Beilock et al., 2002). This added attention decouples proceduralized routines and creates new opportunity for error (Flegal & Anderson, 2008). The present study expands on the notion of procedural memory in high-level athletic skill by looking to recent work in the AoA literature, which suggests that reliance on sensorimotor processes changes across development.

AoA Effects

AoA effects have been identified in several domains, including music, vocabulary acquisition, and second language learning (Hernandez & Li, 2007). In the music domain, there is evidence that early training plays a role in both behavioral performance and neural representations when musicians perform musical and nonmusical tasks. Musically speaking, there is evidence that absolute pitch, the ability to identify a tone in isolation, can be learned by speakers of nontonal languages only before the age of 7 (Deutsch, Henthorn, Marvin, & Xu, 2006; Trainor, 2005). Furthermore, early musical training improves performance on visual perceptual tasks. Two groups

of professional musicians were asked to synchronize finger motor responses with a flashing square. The results revealed significant differences between groups who had been given early and late musical training. Specifically, early-trained musicians were able to better maintain the synchrony between the visual stimulus and their motor response relative to late-trained musicians. The groups were carefully matched such that they differed in the age at which they began playing a musical instrument but not years of musical experience, years of formal training, or hours of current practice (Watanabe, Savion-Lemieux, & Penhune, 2007). Evidence from neuroimaging studies confirmed that early musical training is associated with an increase in the size of motor regions of the cortex showing neural activity during somatosensory stimulation (Elbert, Pantev, Wienbruch, Rockstroh, & Taub, 1995). In a similar vein, Schlaug, Jancke, Huang, Staiger, and Steinmetz (1995) found the anterior corpus callosum to be larger in musicians than nonmusicians and largest for those who learned to play before the age of seven. Thus, early musical learners show changes in behaviors and neural responses that are involved with basic sensory and motor function. These results are consistent with the view that the age of initial musical training influences the amount of sensorimotor processing used in both music and nonmusic tasks.

Effects of AoA have also been found in the language domain. AoA effects on word recognition in monolinguals have been established for more than 30 years (Carroll & White, 1973; Gilhooly & Watson, 1981). Using a number of experimental paradigms, researchers have shown that the age of word acquisition significantly affects the speed and accuracy with which words are accessed and processed (Barry, Morrison, & Ellis, 1997; Cuetos, Ellis, & Alvarez, 1999; Ellis & Morrison, 1998; Gerhand & Barry, 1998, 1999; Gilhooly & Gilhooly, 1979; Lewis, 1999; Meschyan & Hernandez, 2002; Morrison, Chappell, & Ellis, 1997; Morrison & Ellis, 1995, 2000). In general, it has been found that late-learned words tend to elicit longer response times than early-learned words in word reading, auditory and visual lexical decision making, picture naming, and face recognition.

Studies using neuroimaging have elucidated the possible locus of differences in processing late- and early-learned words in monolinguals. In a seminal

study, Fiebach, Friederici, Müller, von Cramon, and Hernandez (2003) asked monolinguals to make lexical decisions to early- and late-learned words while being scanned with functional magnetic resonance imaging. Results in both the visual and auditory modalities revealed greater activity for late- relative to early-learned words bilaterally in the inferior frontal cortex, areas that are involved in effortful or strategic activation of information from the semantic knowledge system (Fiez, 1997; Thompson-Schill, D'Esposito, Aguirre, & Farah, 1997). Early-learned words revealed neural activity in the primary auditory cortex and precuneus. An interesting implication of this result is that declarative memory may play a strong role in learning words late in life, whereas auditory processing may play a strong role in learning words early in life. That is, early learning relies to a greater extent on sensorimotor processing.

In the second language domain, there is also ample evidence of AoA effects. For many years, behavioral studies have shown clear differences between early and late learners of a second language. Most importantly, a number of studies have found an AoA on the ultimate attainment of a second language (L2; Flege, Munro, & MacKay, 1995; Flege, Yeni-Komshian, & Liu, 1999; MacKay & Flege, 2004; Munro, Flege, & MacKay, 1996). Although critical period effects in L2 learning are still being debated (Hakuta, Bialystok, & Wiley, 2003; Harley & Wang, 1997; Johnson & Newport, 1989; Liu, Bates, & Li, 1992; Snow & Hoefnagel-Höhle, 1978), researchers generally agree that late compared with early learning of L2 is associated with lower ultimate proficiency, even though some individuals may achieve native-like proficiency (Birdsong, 1992). Interestingly, L2 AoA affects the processing of syntax, morphology, and phonology more than lexical and semantic processing (Johnson & Newport, 1989; Weber-Fox & Neville, 1996). This is consistent with the notion that certain parts of language may be more based on auditory processing than others.

To account for these differences, Hernandez and Li (2007) proposed that early learning occurs using more sensorimotor processing relative to late learning. One idea is that the learning of a task later in life requires more overt or explicit cognitive processing, and therefore this task will be less dependent on implicit or procedural memory processes than tasks

acquired earlier. However, to date no study has investigated whether these effects are also present in other motor domains, such as sport. If the sensorimotor hypothesis extends to sport, then differences in reliance on explicit and implicit (i.e., proceduralized) memory during skill execution should differentiate early and late learners even when they are equated for overall skill. Specifically, early learners should rely to a greater extent on more implicit memory, whereas late learners should rely on explicit memory when executing a simple sensorimotor skill. As a result, being asked to explicitly attend to what one is doing should impede early learners more than late learners (i.e., because this requires bringing proceduralized skill processes into working memory) and vice versa for a task that takes attention away from performance.

We tested these ideas in the current work. Specifically, we asked a group of skilled golfers who learned to play golf before (early learners) or after (late learners) the age of 10 to take a series of putts on an indoor putting green. Golfers putted in isolation (single-task condition), while monitoring a stream of words presented over a loudspeaker (dual-task condition), or while being instructed to attend to specific aspects of their golf swing (skill-focused condition).

EXPERIMENT

METHOD

We asked 20 skilled right-handed male golfers (all less than 35 years old) to perform a putting task on an indoor green. Golfers had 6–22 years of golf experience ($M = 12.05$, $SE = .89$) and started playing at 5–15 years of age ($M = 10.25$, $SE = .54$).

Participants were instructed to putt a golf ball as accurately as possible to a target, marked by a square of red tape, on which the ball was supposed to land. Participants putted on a standard, flat putting green. There were five different starting locations spaced at three different distances from the target. Two locations were 120 cm from the target (on opposite sides of the green), one location was 140 cm from the target, and two locations were 160 cm from the target (on opposite sides of the green).

Putting took place under three conditions, with order counterbalanced across participants. In the single-task condition, participants putted in isolation. In the dual-task condition, participants monitored a set of random words presented over a loudspeaker for a

prespecified target word while putting. Words were presented at a rate of one word every 3 s, with the target word occurring once randomly every 12 s. The recorded words were composed of monosyllabic concrete nouns randomly selected from the Brown corpus (Kučera & Francis, 1967). In the skill-focused condition, participants were asked to pay attention to their swing, keeping the club head straight during the backswing and through ball contact (Beilock et al., 2002). To make sure that they paid attention to their swing, participants were instructed to say the word “straight” aloud as they completed their follow-through.

In each condition, participants took 20 putts (four putts from each of the five starting locations). Everyone putted in the same fixed random order of starting locations. An experimenter recorded putting accuracy and any failures to repeat the target word out loud (in the dual-task condition) or failures to say “straight” (in the skill-focused condition).

RESULTS

We first performed a median split on golfers’ AoA, which yielded an early group (AoA \leq 10 years, $M = 8.75$, $SE = .48$) and a late group (AoA $>$ 10 years, $M = 12.50$, $SE = .46$). These groups had significantly different AoAs, $F(1, 18) = 28.76$, $p < .001$, but did not differ in terms of age (early learners: $M = 21.33$, $SE = .82$; late learners: $M = 23.75$, $SE = 1.72$), years of golf experience (early learners: $M = 12.58$, $SE = .76$; late learners: $M = 11.25$, $SE = 1.96$), or Professional Golfers’ Association handicap (early learners: $M = 24$, $SE = 10$; late learners: $M = 18$, $SE = 3$), $F_s < 2$.

We next looked at putting errors (mean distance the ball stopped from the target in each putting condition) in a 3 (condition: single-task, dual-task, skill-focused) \times 2 (AoA: early learners, late learners) ANOVA. This analysis revealed a significant condition by AoA interaction, $F(2, 36) = 6.57$, $p < .004$.

Putting error did not significantly differ as a function of AoA across the single-task (early learners: $M = 16.43$, $SE = 1.01$; late learners: $M = 17.87$, $SE = 1.47$) or dual-task (early learners: $M = 15.81$, $SE = 1.01$; late learners: $M = 15.71$, $SE = .84$) conditions, $F_s < 1$. However, early learners’ putting error ($M = 20.17$, $SE = 1.54$) was significantly higher than late learners’ putting error ($M = 15.49$, $SE = 1.20$) in the skill-focused condition, $F(1, 18) = 4.83$, $p < .05$.

Put another way, AoA was not related to putting error in the single-task, $r = -.05$, $p > .82$, or dual-task,

$r = -.27$, $p > .25$, conditions. Yet there was a significant relationship between AoA and skill-focused putting error, $r = -.49$, $p < .03$. The earlier one learned golf, the higher one’s putting error in the skill-focused condition, even when single-task performance was partialled out, $r = -.49$, $p < .04$.

Even in skilled golfers, the age at which training commences plays a role in the memory processes supporting performance. Despite equal performance under single-task conditions, early learners suffer when asked to attend to a component process of performance, suggesting that they rely more heavily on proceduralized skill representations than late learners. Indeed, as seen in Figure 1, across all golfers the extent to which performance was affected by the skill-focused condition relative to the dual-task condition (skill-focused minus dual-task putting error) was related to AoA, $r = -.45$, $p < .05$, but not single-task performance, $r = -.08$, $p > .7$, or Professional Golfers’ Association handicap, $r = .29$, $p > .24$.

Finally, there was no difference as a function of AoA in target words missed in the dual-task condition, $F < 1$, (early learners: $M = .08$ words, $SE = .08$; late learners: $M = 0$ words) or failures to say “straight” in the skill-focused condition, $F = 1$ (early learners: $M = .17$ failures, $SE = .11$; late learners: $M = .38$, $SE = .18$). Thus, our putting accuracy results do not seem to be the product of a trade-off with the performance of any other components of the dual-task or skill-focused conditions.

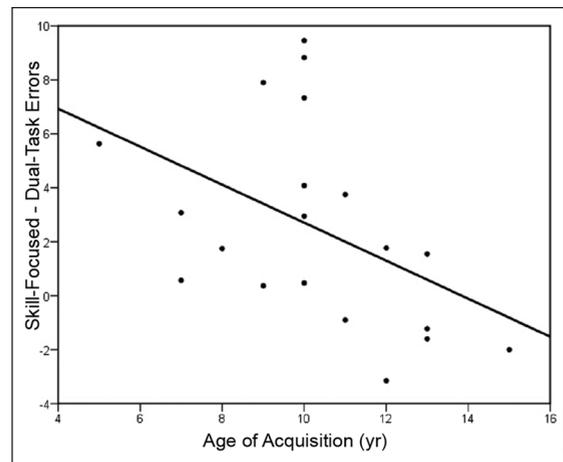


FIGURE 1. Relationship between age of acquisition and skill-focused minus dual-task putting errors. A higher score on the y-axis indicates worse performance in the skill-focused versus dual-task condition. $r = -.45$, $p < .05$

DISCUSSION

The results of our study partially confirmed our hypotheses. Early learners were more disrupted in the skill-focused condition, which is consistent with the sensorimotor hypothesis outlined earlier. We found an interaction between age of acquisition and condition. Whereas both AoA groups performed equally well in the single-task and the dual-task putting conditions, there were significant differences between groups in the skill-focused condition.

These data have interesting similarities and differences with previous studies conducted by Beilock and colleagues (Beilock et al., 2002). In an earlier study, novice and expert golfers were asked to perform the single-task, dual-task, and skill-focused putting conditions used in the current work. Results demonstrated a group \times condition interaction, similar to the one observed in the present study. In Beilock et al., experts performed worse in the skill-focused condition than in the dual-task condition, similar to early golf learners in the present study. Novices in Beilock et al. showed the opposite pattern, performing worse in the dual-task than in the skill-focused condition. This latter finding does not parallel the performance of the late learners in the current work, who performed at an equivalent level of accuracy across all three conditions. Nonetheless, similar to expert golfers, early learners showed reduced accuracy in the skill-focused condition, whereas late learners did not, suggesting that starting golf early leads to a more implicit, proceduralized skill representation than starting later, despite similar levels of overall experience. Finally, our results speak to previous views of the nature of early and late learning. As previously noted, the sensorimotor hypothesis views early learning as involving more perceptual and motor systems relative to late learning. Late learning, on the other hand, should involve cognitive processing to a greater extent. The sensorimotor hypothesis offers an interesting parallel to the implicit–explicit distinction that has been proposed by Beilock and colleagues to account for differences in motor skill execution between expert and novice athletes.

The data in the present study are consistent with the view that early learners use more implicit memory than late learners. Discussion in the developmental memory literature has also conceptualized

age-related changes as having to do with changes in explicit and implicit memory. For example, Reber (1993) proposed that implicit memory develops early in childhood and is invariant during these early years, relying for the most part on earlier developing subcortical neural circuits. However, explicit memory, which relies to a greater extent on cortical brain areas, increases across childhood and well into adulthood. Thus, adults come to rely to a greater extent on explicit memory as they grow older. In this view, development can be seen as a shift from reliance on implicit memory in early childhood to explicit memory later in childhood. Although some studies support the view that implicit memory is invariant across childhood (Meulemans & Van der Linden, 1998), others have found evidence for changes in implicit memory across development (Thomas & Nelson, 2001). Despite this mixed evidence, results still support the view that declarative memory develops across childhood (for a review see Bauer, 2008).

This notion that children differ from adults in the use of declarative memory fits in nicely with a recent study of a motor skill learning task believed to rely largely on implicit memory. Savion-Lemieux, Bailey, and Penhune (2009) asked participants to perform a motor skill learning task in which visual stimuli were associated with different finger responses. The investigators measured both accuracy and response synchronization (i.e., reaction time). Results revealed that accuracy in pressing the correct key when presented with a visual stimulus showed greater improvement across several days of practice in younger children than in older children and adults. The speed to synchronize visual stimuli with motor responses improved with practice across sessions even in adulthood. On the surface, these findings appear to contradict the view that adult–child differences lie on an explicit–implicit continuum because both accuracy and reaction time improved on a task thought to tap into implicit learning mechanisms. However, if one views this motor task and others as involving a mix of different skills that lie on the implicit–explicit continuum, then these results do not contradict notions about adult–child differences in reliance on explicit and implicit memory systems. Specifically, it may be that even though the experiment involves an “implicit” task, adults may be relying on explicit memory to a greater extent than children to complete the task. In

contrast, children may be relying on a less declarative form of memory when performing the task. In other words, both adults and children may be relying on both forms of memory, just to different extents.

This view of the Savion-Lemieux et al. (2009) study may help explain our current data. Early learners showed less accuracy during the skill-focused than the dual-task and single-task putting condition, whereas the late learners showed equivalent performance in all three conditions. The skill-focused condition may have stressed component processes of a sensorimotor chunk in a group that relies to a much lesser extent on declarative memory. This result is also resonant with the sensorimotor hypothesis, which suggests that early learning involves the use of perceptual-motor circuits to a greater extent.

The fact that late learners did not show differences in any of the three conditions is less compatible with the explicit-implicit distinction. If the differences between early and late learners were fully compatible with the use of different memory systems, then we would expect late learners to be less accurate in the dual-task condition than early learners. This crossover interaction would be similar to the one observed when comparing experts and novices in Beilock et al.'s (2002) previous work. However, it may be that, similar to adults in the Savion-Lemieux et al. study, late learners rely on a mix of implicit and explicit processes that do not lead to decrements in the skill-focused condition (as seen in the early learners) but also do not result in disruption in the dual-task condition. Future work is needed to explore this possibility in more detail.

Another potential reason for the lack of greater differences between early and late learners in the current experiment could be the dependent measures used. The use of accuracy, a measure that is very reliable in adults and shows weak learning effects, might have not allowed us to observe effects that differ in late learners relative to early learners. An analogous measurement to that used by Savion-Lemieux et al. (2009) would have been to observe the speed with which the components of the swing were assembled or to capture a measurement of reaction time. Because both groups are expert putters, we might find differences in late learners via different measurements that can accurately capture differences in swing patterns.

The current results also extend beyond memory representations to one's potential for success under stress. A prominent theory of choking in sports suggests that when the pressure is on, in an effort to control performance and ensure success, athletes try to access explicit skill knowledge that disrupts the fluid execution of proceduralized skill routines (Beilock & Carr, 2001). Having less explicit knowledge to begin with may reduce one's tendency to monitor execution under pressure. Indeed, Liao and Masters (2001) showed that learning that minimizes the buildup of explicit skill knowledge in the first place prevents pressure-induced failure, possibly because athletes are less likely to try to access explicit skill rules they do not have. In terms of the current work, this points to learning golf early as a possible mechanism to reduce pressure-induced performance decrements.

Of course, when asked to specifically attend to a component process of putting (as in the skill-focused condition here), those who represent their skill in a more proceduralized fashion (early learners) may perform more poorly than those who do not (late learners) precisely because the former group is not used to thinking about their performance in this explicit way (Beilock & Carr, 2001; Jackson, Ashford, & Norsworthy, 2006). But under stress, when people are not being specifically instructed to attend to the instantiation of their putt, early learners' heavy reliance on implicit memory processes may make them less likely to do so and thus (like Tiger Woods) more poised for success.

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