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Age of Acquisition in Sport: Starting Early Matters

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Abstract

Although the age at which a skill is learned (Age of Acquisition or AoA) is one of the most studied predictors of success in domains ranging from language to music, to date 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 loud-speaker (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 condition. 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.

Keywords

Age of Acquisition; Motor-skill learning; Memory; Development

Age of Acquisition in Sport: Start Early and Practice Often

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) impacts athletic performance. Here we provide the first demonstration that early learners of golf differ from late learners in terms of the memory processes supporting 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, 1993; 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 & Perlmuter, 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 within the age of acquisition literature, which suggests that reliance on sensorimotor processes changes across development.

AoA

AoA effects have been identified across 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 non-musical tasks. Musically speaking, there is evidence that absolute pitch, the ability to identify a tone in isolation, can only be learned by speakers of non-tonal languages before the age of 7 (Deutsch, Henthorn, Marvin, & H-S., 2006; Trainor, 2005). Furthermore, early musical training also 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 initiated playing a musical instrument but not years of musical experience, years of formal training and hours of current practice (Watanabe, Savion-Lemieux, & Penhune, 2007). Evidence from neuroimaging studies has 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 et al. (1995) found the anterior corpus callosum to be larger in musicians than non musicians, and largest for those who learned to play before the age of seven. Hence, 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 non-music tasks.

Effects of AoA have also been found in the language domain. Age of acquisition effects on word recognition in monolinguals have been established for over thirty 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 slower response times than early learned words in word reading, auditory and visual lexical decision, 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, Mueller, von Cramon, and Hernandez (2003) asked monolinguals to make lexical decisions to early and late learned words while being scanned with fMRI. Results in both the visual and auditory modalities revealed increased 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 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, 1995a, 1995b; Flege, Yeni-Komshian, & Liu, 1999 & 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 to 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 thus 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, if asked to explicitly attend to what one is doing, this should hurt early learners more so than late learners (i.e., because this requires bring 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 loud-speaker (dual-task condition), or while being instructed to attend to specific aspects of their golf swing (skill-focused condition).

Method

To test this, we asked 20 skilled right-handed male golfers (all <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).

Individuals 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 120cm from the target (on opposite sides of the green), one location was 140cm from the target, and two locations were 160cm from the target (on opposite sides of the green).

Putting took place under three conditions, order counterbalanced across participants: (1) Single-Task condition: individuals putted in isolation. (2) Dual-Task condition: participants monitored a set of random words presented over a loudspeaker for a pre-specified target word while putting. Words were presented at a rate of one word every three seconds, with the target word occurring once randomly every 12 seconds. The recorded words were composed of monosyllabic concrete nouns randomly selected from the Brown corpus (Kucera & Francis, 1967). (3) 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 each participant paid attention to their swing, individuals were also 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 as well as 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≤10, M=8.75, SE=.48) and a late group (AoA>10, M=12.50, SE=.46). These groups had significantly different AoA’s, $F(1,18)=28.76$, $p<.001$, 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 PGA handicap, (Early Learners: M=24, SE=10; Late Learners: M=18, SE=3), Fs<2.

We next looked at putting errors (mean distance the ball stopped from the target in each putting condition, cm) in a 3(condition: Single-Task, Dual-Task, Skill-Focused) x 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, Fs<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 relation 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 impacted by the Skill-Focused condition relative to the Dual-Task condition (Skill-Focused minus Dual-Task putting error) related to AoA, $r=-.45$, $p<.05$, but not Single-Task performance, $r=-.08$, $p>.7$, or PGA 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.

Discussion

The results from our study partially confirmed our hypotheses. Early learners were more disrupted in the skill-focused condition, which is consistent with the sensorimotor hypothesis outlined in the introduction. 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 x condition interaction, similar to the one observed in the present study. In Beilock et al., experts performed worse in the skill-focused condition relative to 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 relative to 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. We discuss possible reasons for this difference below. Nonetheless, similar to expert golfers, early learners show reduced accuracy in the skill-focused condition, whereas late learners do 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 relative to 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) has proposed that implicit memory develops relatively 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. Hence, adults will 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 used fits in nicely with a recent study in a motor-skill learning task believed to rely largely on implicit memory. Savon-Lemieux and colleagues 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 relative to older children and to adults. The speed to synchronize visual stimuli with motor responses improved with practice across sessions even in adulthood. These findings, on the surface, appear to contradict the view that adult/child differences lie on an explicit/implicit continuum since 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/implicit memory systems. Specifically, it may be that even though the experiment involves an “implicit” task, adults may be relying to a greater extent on explicit memory relative to children to complete the task. In contrast, children may be relying on a less declarative form of memory when conducting 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 Savon-Lemieux study may help explain our current data. Early learners showed decreased accuracy during the skill-focused relative to 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 that 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 relative to 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 Savon-Lemieux 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 either. 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 due to the dependent measures used. The use of accuracy, a measure which is very reliable in adults and shows relatively 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 employed by Savion-Lemieux would have been to observe the speed with which the components of the swing were assembled or to capture a measurement of reaction time. Since 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, athletes, in an effort to control performance and ensure success, try to access explicit skill knowledge that disrupts the fluid run-off of proceduralized skill routines (Beilock & Carr, 2001). Having less explicit knowledge to begin with may downgrade one's tendency to monitor one's execution under pressure. Indeed, Liao and Masters (2001) have shown that learning that minimizes the build-up of explicit skill knowledge in the first place prevents pressure-induced failure – possibly because athletes are less prone to try and 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 individuals 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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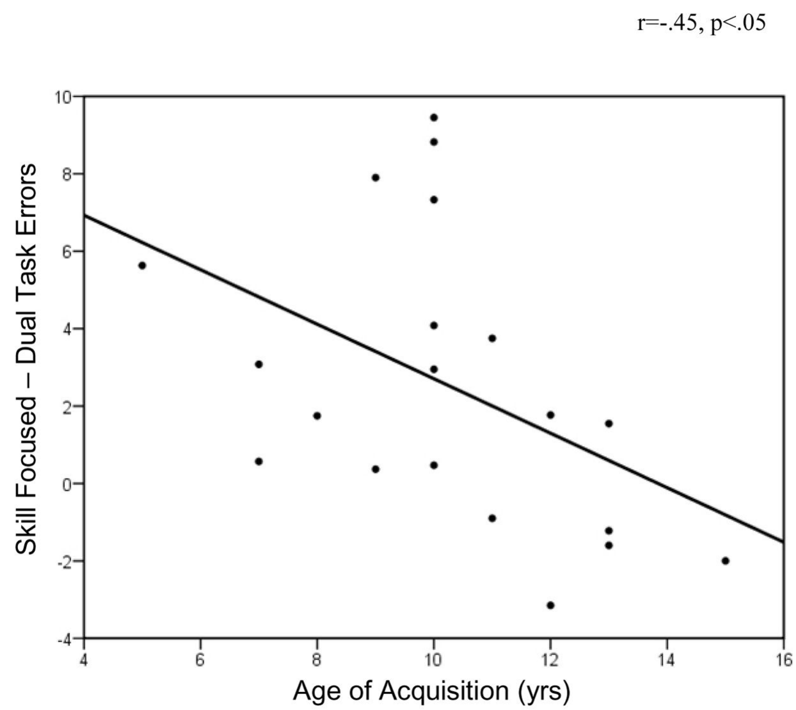

Figure 1.

Relation between Age of Acquisition (AoA) and Skill-Focused minus Dual-Task Putting errors. A higher score on the y-axis is indicative of worse performance in the Skill-Focused versus Dual-Task condition.