

Animal Models of Expertise Development

William S. Helton (Deak_Helton@Wilmington.Edu)

Department of Psychology, 251 Ludovic Street
Wilmington, OH 45177 USA

Abstract

There is a continuing debate in the psychological literature between those who lean more towards learning theories of expertise development and those leaning more towards talent theories. However, the development of human expertise has not been open to direct experimental methods and will probably continue to elude experimentalists in the future. A promising alternative is to employ non-human animal models. Expertise researchers have seemingly overlooked this possibility. However, there are studies in the animal behavior literature that address the development of non-human animal expertise without specifically referring to the topic as expertise. I will discuss two non-human animal examples of expertise development that have been researched by ethologists. Non-human animal expertise development, unlike human expertise development, is subject to direct experimentation. Hence, I recommend initiating expertise research with non-human animals.

Sternberg (1999) proposes that intelligence is a type of developing expertise, which if true would indicate the ubiquity of expertise in all human affairs. Skoyles (1999) argues that the environmental demands for the development of expertise were the primary catalysts for the rapid increase in brain size among early homo ancestors. Expertise is, no doubt, an important area of psychological research that is increasingly expanding its horizons. However, human expertise research has been haunted historically by two fundamental problems: first, a functional definition of expertise and second, how expertise is developed. In this paper, I will be addressing the second issue, the development of expertise. There is a continuing debate between those who lean more towards learning theories of expertise development and those leaning more towards innate talent theories. Researchers from both perspectives acknowledge that the other plays some role in expertise development; only straw-men argue that expertise does not require some innately inherited architecture or that expertise can develop without any learning at all. The debate is over the degree to which talent or learning determines the development of expertise. The majority of expertise researchers currently favor a stronger input from learning (Ericsson, 1996; Ericsson & Charness, 1997; Howe, Davidson, & Sloboda, 1998); however, this position is not without critics (Gardner, 1997; Winner, 1996).

There appears to be no realistic way to determine the extent to which learning or inherent talent influences human expertise development. Although data has been gathered to support one position or the other, the data has not been decisive. The data is only suggestive because it is correlational in nature. Experiments that truly test competing theories of expertise development, for practical and ethical reasons, cannot be employed with humans. However if we take evolution seriously, then the continuity of species suggests to us a proper means to investigate the issue of expertise development, namely, the employment of non-human animal models.

Preliminary Remarks on Expertise

Definition of Expertise

I will not attempt to provide a solution to the first historical problem of human expertise research, a proper definition of expertise, in this paper. However, for non-human animal models to be a viable solution for the problem of expertise development, it must be demonstrated that animals' performance satisfies the proposed definitions of expertise that are popular in the human literature. Currently, there are two modal definitions of expertise proposed in the human literature: either expertise is the matching of a preset criterion level of performance for a skill, or expertise is being in the top 5% of performers of a skill. Personally, I agree with Wagner and Stanovich (1996) in their belief that defining expertise as exceptional performance, being in the top 5% of performers in a domain, is wrong headed, and that a more proper definition is the matching of a preset criterion-level of performance. Nevertheless, by either definition of expertise, pre-select criterion or top 5% of performers, animals would satisfy the definition on a variety of skills. For example, the top 5% of greyhound track runners, or greyhounds that can run some distance at a pre-select speed.

Failure of Human-centered Approaches

According to Ericsson (1996), phenomena can be studied via scientific methods when they meet these three criteria: (1) the phenomena occur reliably in clearly specified situations with distinctive observable characteristics, (2) the phenomena should be reproducible under controlled conditions, and (3) the phenomena should

be predictable and describable by objective measures. Ericsson provides detailed information on how human expert performance meets these criteria. However, Ericsson acknowledges that the development of human expertise does not yet meet these criteria. Human expert performance is reliable, reproducible, and predictable in laboratory tests, but the development of human expertise has not been fully open to these laboratory techniques.

Shiffrin (1996) indicates that finding a suitable experimental design is a formidable task. Expertise takes a long time to develop; it consumes a large percentage of the life span of an organism. In humans, the development time is considered to be roughly ten years for most domains (Ericsson, 1996). Designing an experiment in which individuals are randomly assigned to different training conditions for a long period of time, up to possibly ten years, without many participants dropping out is enormously difficult. Shiffrin suggests marksmanship in the military as a possible way to conduct such a long involved experiment, however, there are limitations to this proposal, in that there may be a selection bias. People that join the military, especially for combat arms units, are likely to be interested in marksmanship; they may be already motivated to excel in marksmanship. A primary problem with human studies of expertise development is they are hopelessly confounded by the participants' willingness to partake in the training. The unfortunate reality is the participants' willingness to stay in the experiment, to continue training, may be due to their ease of mastery, or what many call talent. Hence, the role of talent in expertise development continues to irk researchers promoting the strong learning view. Although researchers can learn a great deal about expertise by studying humans, an exclusive human focus will leave many questions unanswered.

Animal Models of Expertise Development

Most conceivable attempts to design proper experiments of human expertise development are going to fail, because of realistic or ethical constraints. An alternative solution is to employ non-human animal models. Using non-humans to study learning and intellectual development has proven enormously informative historically (Harlow & Mears, 1979). Extensive studies have been conducted on 'skill' development and learning in non-humans (Hikosaka, Miyachi, Misyashita, & Rand, 1996). Expertise researchers, however, have seemingly overlooked the relevance of the work to their field. In order to elucidate the potential of non-human research, I will provide two examples of expert models: asymmetric orb-web construction by predatory spiders and narcotic detection by canines. The two examples discussed do not describe actual expertise development experiments; they are comprised of recent ethological studies serving as indicators of what may be done in future research. The examples are not definitive; a myriad of other non-human examples could have been selected. Hopefully they are suggestive of the range of potential models available, from simple to complex.

Web Construction

A splendid animal model for the development of expertise in a non-human organism is the construction of orb-webs by predatory spiders. A common feature of orb-webs is their structural 'top/bottom' asymmetry (Herberstein & Heiling, 1999). The lower web region is often larger than the upper web region in many species of orb-web spiders. Orb-web spiders are not active foragers. They waste very little energy in actively seeking out prey; however, they expend a great amount of energy in the construction and maintenance of their complex traps, webs. Because of this immense energy expenditure, orb-web spiders become expert web builders. The expenditure of effort required to build a web is so great that the allowance for too many mistakes would be fatal for the species. Nature is not very forgiving to the unskilled.

The value of web asymmetry is improved prey capture, due to the speed advantage a spider has in detecting and reaching prey captured below the hub. Orb-web spiders wait in the hub or center of their web facing downwards. Spiders are quicker in detecting vibration sources when directly oriented toward them. A spider will reorient itself to face a source of vibration, similar to a person, who turns toward an object when it is detected in the periphery of the visual field. Also, spiders are slower at reaching prey above the hub, because of the pull of gravity. For these reasons, asymmetric web construction increases the spider's chance of capturing prey, and this is adaptive.

Spiders are invertebrates with comparatively small and 'primitive' nervous systems. They are generally regarded to have a limited capacity to acquire and retain information gained through experience (Heiling & Herberstein, 1999). However, many invertebrates meet the requirements of associative learning, and learning is currently regarded as a fundamental neural process that does not require complex neural structures (Dukas, 1998). Spiders can learn, although their plasticity is currently considered to be limited in comparison to vertebrates, like humans. Orb web asymmetric construction was until recently largely considered to be genetic or due to physical constraints. Behavioral ecologists are only recently exploring the role of learning in web construction. Physical constraints have been known to effect web asymmetry; for example, increasing the spider's weight either artificially or naturally increases the amount of asymmetry (Herberstein & Heiling, 1999). The amount of asymmetry also varies by species, possibly indicating some genetic or hardwired elements. Although physical constraints and genetics do affect asymmetric web design, it is partially learned by spiders (Heiling & Herberstein, 1999).

Juveniles of several orb-web spider species are known to construct perfectly symmetrical webs, whereas, mature spiders of the same species construct asymmetric webs, even when weight is controlled. Web asymmetry in some species seems to be the result of learning; the spiders become more efficient web designers over their life history. Via experimental manipulation, Heiling & Herberstein were

able to empirically test the hypothesis that asymmetry is learned. They observed that spiders do learn to construct asymmetric webs, via feedback about the capture rates of locations on their webs. The process is more involved than classical conditioning. The spiders designed their webs based on information about capture rates independently of food reward. The design shape of the web was not contingent on the spider's consuming the prey captured by the web, but on their knowledge of which locations on the web lead to the capture of more prey.

Based on appearances, spiders are very different from humans. However, as a model of expert development, they are informative. Asymmetrical web construction can be classified as expertise by either definition of expertise: either a pre-select criteria of amount of asymmetry or the top 5% of asymmetrical web construction. The development of asymmetric web construction occurs reliably in clearly specified situations with distinctive observable characteristics, is reproducible under controlled conditions, and is predictable and describable by objective measures. Hence, meeting the criteria outlined by Ericsson (1996) for phenomena to be studied via scientific methods. Even for an organism considered to be as simple as a spider, learning or the interaction with the environment plays an important role in developing expertise. But even a spider with no experience can construct a functional web. Genetics does control a great amount of the abilities of a spider.

Narcotic Detection

Constructing a web is directly necessary for the survival of orb-web spiders, but many skills developed by people are not. Most of the domains investigated by human expertise researchers are not survival skills. The development of skills with immediate survival value may be qualitatively different from skills that are more indirectly adaptive or for skills that are not adaptive at all. At least someone could raise the objection that expertise only refers to non-survival skills, where there would be a minimum amount of genetic hardwiring. To alleviate this objection another model from the animal kingdom can be proposed: the development of skills among canines, in particular narcotic detection.

Dogs are extremely versatile social animals. They share the longest historical social bond with humans, and may be the only domesticated species that was not actually forced into domestication (Prestrude & O'Shea, 1998). Dogs are trained and put to use in a variety of disciplines, including, arson detection, blind assistance, epilepsy detection, forensic tracking, guarding, hearing-aid assistance, lure racing, narcotic detection, retrieving, search & rescue, sheep herding, sled racing, weight pulling, etc. The similarity between canine skills and human skills should be obvious. What is the difference between a human track runner and a greyhound racer, besides the fact that the greyhound is faster?

The ability of a dog to detect narcotic substances is not historically a survival skill for that species. However,

some dogs do become particularly skilled at detecting narcotic substances. Granted, the ability to detect some substances via scent, such as tracking prey, may have been historically a survival skill. But the ability to smell things in general is not the ability to distinguish between narcotic substances and other scent sources in a complex environment, like a ship, airport, or under a bus. Likewise, the ability to distinguish between objects via visual information was probably a survival skill for early humans, but that does not imply that the ability to distinguish between specific letters on a page of many letters ever was.

Narcotic scent detection is a complicated skill. In regards to narcotic detection, not only is the scent environment extremely complicated for a dog (imagine all the scents in an airport), but also the smuggler is probably trying to hide the narcotic substance and its scent. The training required to detect a narcotic substance is very involved. A relevant issue for expertise development is how much of the skill is trainable, and how much of it requires innate abilities. Slabbert and Rasa (1997) conducted an experiment to determine the effect puppies observing maternal narcotic detection had on their later skill development. German shepherd pups from untrained and trained narcotic detection bitches were separated into two groups: those separated from their mothers at 6 weeks and those separated from their mothers at 3 months. The pups reared by trained bitches in the extended maternal group (3 months) were allowed to observe their trained mothers work between the ages of 6 and 12 weeks. When the groups were later tested for narcotic detection aptitude at age 6 months, the observational group did significantly better than the other groups. Of the observational group, only 15% failed the aptitude test, whereas, in the other groups 81% failed. Early learning and inspiration, a proper role model, does seem to play a very significant role in the ability to acquire the skill. The power of an early role model demonstrated in this study may provide some insight into the phenomena of expertise running in human families, such as the musical skills of the Bachs or the mathematical skills of the Bernoullis.

Nevertheless, 15% of the observational group still failed to pass the preliminary aptitude test, let alone develop "true" expertise. Obviously, the skill requires that the dog have a functioning nose, the ability to learn to distinguish scents, and the hard to define quality, motivation to do the task. All of the dogs were German shepherds, regarded as one of the most trainable breeds, from a reputable police breeder, suggesting prior 'artificial' selection for a predisposition to work. Even with a role model and early encouragement, some of the dogs still seem disinterested in doing the task. This disinterest may be due to individual genetic variation in temperament or motivation.

Dogs are closer to humans in capacity and in skills than spiders. As a model of expert development, canine narcotic detection is excellent because like many human skills it is not directly adaptive, and is complicated, taking a lot of formal training to develop. Unlike asymmetric web

construction, but similar to many human skills, narcotic detection is not self-taught. Also from a practical point of view, there is a large potential provider of funds for research on the development of this skill, namely law enforcement agencies. Narcotic detection can be classified as expertise by either definition of expertise: either a pre-select criteria or the top 5% of detectors. The development of narcotic detection occurs reliably in clearly specified situations with distinctive observable characteristics, is reproducible under controlled conditions, and is predictable and describable by objective measures. Hence, meeting the criteria outlined by Ericsson (1996) for phenomena to be studied via scientific methods.

Discussion

At least in respect to the visual arts, Winner (1996) argues that talent precedes the hard work that leads to high achievement. Winner argues that at least in some cases certain individuals are born with a “rage to master.” It may be that there is no gene or set of genes for artistic talent, just as it is unlikely that there is a particular set of genes that determine a dog’s capacity to make a good narcotic detector. There probably are genes that regulate the architecture that is necessary to master a skill, like a good nose in the case of the narcotic detector, and there may be genes that regulate the motivation or personality that are necessary to truly master a domain. Research with skilled dogs may provide some of these answers, as they seem to provide a good model for human expertise, and they can be controlled genetically via selective breeding and environmentally via living conditions, early role models, etc.

I suggest the utilization of skilled canines as research models of expertise development primarily because they are very practical; my point is not that canines are the only example of genuine animal expertise. There are many examples of non-human expert models, including two species that might ‘instruct’ the skill: chimpanzees and killer whales.

According to Parker (1996, p.361), “Chimpanzee mothers expend considerable parental effort apprenticing offspring to use tools to extract high energy food resources.” Some chimpanzees fish for insects. The chimpanzee constructs a wand by selecting a twig or grass stem and modifies it by removing its leaves. The chimpanzee then proceeds to use the wand to fish for termites or ants. The ability to fish for insects appears to require a high degree of skill, taking a chimpanzee 4-7 years to master. Chimpanzees also appear in some cases to use stone tools to crack open nuts. The efficient technique of nut cracking takes 7-8 years for a chimpanzee youth to master, approaching the rough ten-year period for human expertise development. Both insect fishing and nut cracking appear to involve substantial instruction, similar to many human skills.

Killer whales are known to swim ashore to capture pinnipeds (seals). These killer whales intentionally beach themselves in order to catch their prey. This behavior is

profitable but extremely risky; killer whales are sometimes stranded on the beach, unable to return to deeper water, which leads to their death. To carry off this hunting operation successfully no doubt requires a great deal of skill, or as I would argue the development of expertise. Rendell and Whitehead (2001), in a summary of some recent research, further argue that killer whales in some cases actively teach the skill of intentional beaching to their offspring. Although Rendell’s and Whitehead’s suggestion that killer whales actively teach this skill (or any skill) is controversial, the possibility of a naturally occurring instructed form of non-human animal expertise is intriguing and could prove useful in helping to open the door on further investigations of non-human animal expertise.

Killer whales and chimpanzees, however, would not make easy or convenient research participants in controlled experiments; the cost of housing them alone would most likely prove prohibitive. Many other non-human animal research models of expertise are possible, it merely appears to me that canines because of their diversity of skills, ease of handling, and low cost to house appear to be the most practical choice. Canine expertise is also not only of theoretical interest, but is extremely important in many applied settings, such as narcotic detection, explosives detection, etc.

Certain species, like canines, are more plastic than others, such as spiders; hence some species will be better models for humans, who are highly plastic, than others. However, most species, even very simple ones, have some flexibility. The essential survival skills or building blocks tend to be hard-wired. The ability to construct a web is hardwired into an orb-web spider, but the refinement of the web design seems to be left to learning, at least in some species. The ability of a dog to detect scents is hard-wired. The dog’s olfactory epithelium is one of the largest among animals (Prestrude & O’Shea, 1998). The ability to pick out narcotic scents among all other scents is learned, and trained. But some dogs are easier to train than others, and some dogs do not seem to be able to do it at all. This may be similar to the situation in humans.

For example, Sloboda (1996; 2000) in regard to musical skills argues correctly against the naïve ‘folk psychology’ belief in talent, however, he qualifies his statements, by not denying that inherited differences may play some role in determining to what extent musical skills are acquired. Sloboda acknowledges the lack of data that would determine the inheritability of musical gifts, but advances an alternative view that music is a species-defining characteristic of humans that can be refined by training, like spinning webs is for spiders, or detecting scents for canines. His interest is in why so few humans, who are naturally primed for music, fail to reach a competent level of achievement. It may be that the time demands required to master music may not interest people of certain inherited dispositions. There may have to be an inherited drive to master music. Training may be able to instill the drive in those that do not acquire it genetically.

We do not know, but research similar to Slabbert and Rasa's (1997) with dogs, especially if designed with those issues specifically in mind, may be the way to go about discovering the answer.

Ericsson (1996, p.20) states that, "Even when individuals have access to a similar training environment, large individual differences in performance are still observed." He also indicates that time spent studying a discipline is not a reliable predictor for performance. The discussion of non-human examples of expert development left us with the equally interesting fact: some dogs are better at finding narcotics than others. Species clearly differ, but what about individuals within a species? One of the suppositions of the Darwinian theory of evolution is that the initial variation amongst individuals is what natural selection acts upon. Without variation among individual organisms the game is over. If every member of a species is exactly the same, and a new environmental condition occurs that they cannot handle, the species has ended. The species that is insured against this via individual differences is more likely to survive.

One problem with natural occurring variation is the mechanism by which it comes about. In humans and similar animals, are personality differences due to genes, culture - learning or environmental constraints? Elman et al. (1996) suggests all three, or more specifically, the interaction between all three. The unfortunate reality is that we currently do not know. Likewise, the factors shaping expertise development are not currently known, however, the proper employment of non-human animal models may be able to shine some light on this difficult issue. Non-human animal expertise development, unlike human expertise development, is subject to laboratory experimentation. One may speculate on why non-human animal models have not been suggested earlier. Researchers do not appear to view non-humans as potential experts or expert models, although there seems to be little difficulty in referring to computer programs as 'expert' systems. Perhaps most of us are still uncomfortable with the full implications of Darwin's theory of evolution. Many of us suffer from human separatism, a metaphysical artifact of a religious world-view that promotes the idea that we are closer to angels than to beasts regardless of the mass of empirical evidence against such a view (Holcomb, 1996).

Conclusion

I recommend that psychologists take Darwin seriously and initiate expertise research with non-human animals. The belief that humans are the only species that demonstrate expertise is difficult to maintain in light of the numerous skills non-humans exhibit to such a high degree. To apply the term 'expertise' only to humans would require an arbitrary definition newly created for just such a purpose, which is unnecessary, unless one has a theological axe to grind.

Agnew, Ford, and Hayes (1997) argue that the minimum criterion for expertise is to have a reasonably

large group of people consider the individual an expert. For many non-humans a reasonably large group of people already recognizes their expertise. As early as 945 AD the Welsh laws of Hywel Dda recognized the difference between trained expert dogs and untrained dogs by setting different legal penalties for killing them (Menache, 2000). A more contemporary example is the high price set for trained detector dogs, herding dogs, and service dogs. Also, service dogs have different access rights than non-expert dogs, an explicit legal recognition of their expertise. Moreover, many people, including the author, who live with and appreciate the work of a service dog regard them as experts, thus comprising a reasonably large group considering them as such.

Because of their behavioral flexibility, social similarity to humans, recognized expertise in many fields similar to human's, ease of handling and relatively low economic cost to house, skilled dogs would make excellent expert models. Research with skilled canines may provide insights into human expertise development, at the very least it may provide useful information in the training of canine experts.

Acknowledgments

I thank Dr. Donald Schumsky at the University of Cincinnati for providing critical feedback and editing this article.

References

Agnew, N.M., Ford, K.M., & Hayes, P.J. (1997). Expertise in context: personally constructed, socially selected and reality-relevant? In P.J. Feltovich, K.M. Ford, & R.R. Hoffman (Eds.), *Expertise in context* (pp. 219-244). Menlo Park, CA: AAAI Press.

Dukas, R. (1998). Ecological relevance of associative learning in fruit fly larvae. *Behavioral Ecology and Sociobiology*, 19, 195-200.

Elman, J.L., Bates, E.A., Johnson, M.H., Karmiloff-Smith, A., Parisi, D., & Plunkett, K. (1996). *Rethinking innateness: a connectionist perspective on development*. Cambridge, MA: MIT Press.

Ericsson, K.A. (1996). The acquisition of expert performance: an introduction to some of the issues. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp. 1-50). New Jersey: Lawrence Erlbaum Associates.

Ericsson, K.A. & Charness, N. (1997). Cognitive and developmental factors in expert performance. In P.J. Feltovich, K.M. Ford, & R.R. Hoffman (Eds.), *Expertise in context* (pp. 341). Menlo Park, CA: AAAI Press.

Gardner, H. (1997). *Extraordinary minds: portraits of exceptional individuals and an examination of our extraordinariness*. New York, NY: Basic Books.

Glaser, R. (1996). Changing the agency for learning: Acquiring expert performance. In K. A. Ericsson

(Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp.303-311). New Jersey: Lawrence Erlbaum Associates.

Harlow, H.F. & Mears, C. (1979). *The human model: Primate perspectives*. Washington, DC: V.H. Winston & Sons

Heiling, A.M. & Herberstein, M.E. (1999). The role of experience in web-building spiders (Araneidae). *Animal Cognition*, 2, 171-177.

Herberstein, M.E. & Heiling, A.M. (1999). Asymmetry in spider orb webs: a result of physical constraints? *Animal Behaviour*, 58, 1241-1246.

Hikosaka, O., Miyachi, S., Miyashita, K., & Rand, M.K. (1996). Learning of sequential procedure in monkeys. In J.R. Bloedel, T.J. Ebner, & S.P. Wise (Eds.), *The acquisition of motor behavior in vertebrates* (pp. 303-318). Cambridge, MA: MIT Press.

Holcomb, H.R. (1996). Just so stories and inference to the best explanation in evolutionary psychology. *Mind and Machines*, 6, 525-540.

Howe, M.J.A., Davidson, J.W., & Sloboda, J.A. (1998) Innate talent: reality or myth? *Behavioral and Brain Sciences*, 21, 399-422.

Menache, S. (2000). Hunting and attachment to dogs in the pre-modern period. In A.L. Podberscek, E.S. Paul, & J.A. Serpell (Eds.), *Companion animals & us* (pp. 42-60). Cambridge, UK: Cambridge University Press.

Parker, S.T. (1996). Apprenticeship in tool-mediated extractive foraging: The origins of imitation, teaching, and self-awareness in great apes. In A.E. Russon, K.A. Bard & S.T. Parker (Eds.), *Reaching into thought: The minds of great apes* (pp. 348-370). Cambridge: Cambridge University Press

Prestrude, A.M., & O'Shea, J.G. (1998). Dogs in service to humans. In G. Greenberg & M. A. Haraway (Eds.), *Comparative Psychology: A Handbook* (pp. 386-392). New York: Garland Publishing.

Rendell, L., & Whitehead, H. (2001). Culture in whales and dolphins. *Behavioral and Brain Sciences*, 24, 309-382.

Shiffrin, R.M. (1996). Laboratory experimentation on the genesis of expertise. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp. 337-345). New Jersey: Lawrence Erlbaum Associates.

Skoyles, J.R. (1999). Human evolution expanded brains to increase expertise capacity, not IQ [42 paragraphs]. *Psycoloquy* [on-line serial], 10. Available E-mail: <http://cogprints.soton.ac.uk/>.

Slabbert, J.M., & Rasa, O.A.E. (1997). Observational learning of an acquired maternal behaviour pattern by working dog pups: an alternative training method. *Applied Animal Behaviour Science*, 53, 309-316.

Sloboda, J.A. (1996). The acquisition of musical performance expertise: Deconstructing the "talent" account of individual differences in musical expressivity. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp. 107-126). New Jersey: Lawrence Erlbaum Associates.

Sloboda, J.A. (2000). Individual differences in music performance. *Trends in Cognitive Sciences*, 4, 397-403.

Sternberg, R.J. (1999). Intelligence as developing expertise. *Contemporary Educational Psychology*, 24, 359-375.

Wagner, R.K. & Stanovich, K.E. (1996). Expertise in reading. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp. 189-225). New Jersey: Lawrence Erlbaum Associates.

Winner, E. (1996). The rage to master: The decisive role of talent in the visual arts. In K. A. Ericsson (Ed.), *The road to excellence: The acquisition of expert performance in the arts and sciences, sports and games* (pp. 271-301). New Jersey: Lawrence Erlbaum Associates.