Neuropsychology
2009, Vol. 23, No. 2, 265–269

0894-4105/09/$12.00 DOI:10.1037/a0014553

BRIEF REPORT

Contraction of Time in Attention-Deficit Hyperactivity Disorder

David L. Gilden and Laura R. Marusich
The University of Texas at Austin

Attention-deficit hyperactivity disorder (ADHD) has been associated with anomalies in dopamine systems. Recent advances in the understanding of the core cognitive deficits in ADHD suggest that dopamine dysfunction might be expressed through shortened time scales in reward-based learning. Here this perspective is extended by the conjecture that temporal span in working memory systems might generally be shortened. As a test of this conjecture the authors focus on the implicit memory system involved in rhythmic movement, assessing the minimum tempo at which rhythmic feeling can be sustained in adults with diagnosed ADHD and in a control group of normal adults. The authors found that people with ADHD do in fact have a rhythm cut-off that is faster in tempo than those without ADHD. This finding is consistent with the idea that impaired dopamine dynamics have systemic consequences for cognitive function, essentially recalibrating the clock that sets the time scale for the subjective experience of temporal events.

Keywords: attention deficit, timing, dopamine, musical performance, l/f noise

Attention-deficit hyperactivity disorder (ADHD) is a syndrome that impacts cognitive functions essential to the moment-to-moment apprehension of and response to the environment. An influential cognitive theory of ADHD identifies impairments in the executive control of inhibition as being a principal deficit (Barkley, 1997). Inhibitory control is operationalized through tasks that require the withholding of response: so-called Go/No-Go methods. In one version of the methodology (Conners, 1995), the dependent measures have been standardized to serve as a diagnostic tool. Yet Go/No-Go methods generally fail to generate consistent group differences based on ADHD diagnosis (Castellanos, Sonuga-Barke, Milham, & Tannock, 2006; Edwards et al., 2007). Nevertheless, one prediction of the inhibitory control theory, that ADHD would lead to deficits in temporal aspects of working memory (Barkley, 1997), has led to a number of interesting findings regarding the perception of time and the planning of behavior, delay aversion being most notable (Sonuga-Barke, Saxton, & Hall, 1998). The notion that time perception might be altered by ADHD is supported by neuroimaging evidence of volumetric reductions (Castellanos et al., 2002; Valera, Faraone, Murray, & Seidman, 2007) in areas known to control and regulate timing: prefrontal cortex (Mangels, Ivry, & Shimizu, 1998; Smith, Taylor, Lidzba, & Rubia, 2003) and cerebellum (Ivry & Spencer, 2004; Mangels et al., 1998). Yet, direct psychophysical assessments of time perception have also failed to yield consistent group differences.

David L. Gilden and Laura R. Marusich, Department of Psychology, The University of Texas at Austin.

Financial Support for this research was provided by National Institutes of Mental Health Grant R01-MH58606 and National Science Foundation Grants BCS-0226449 and BCS-0744989.

Correspondence concerning this article should be addressed to David L. Gilden, 1 University Station A8000, Austin, TX 78712. E-mail: gilden@psy.utexas.edu

Timing behavior is generally assessed in ADHD populations through explicit tests in which the participant must focus attention on the passage of time per se. These tests are quite diverse and include anticipating a future event scheduled some few seconds or minutes in the future (Rubia, Taylor, & Taylor, 1999; Smith, Taylor, Rogers, Newman, & Rubia, 2002; Sonuga-Barke et al., 1998), synchronized tapping with an external signal (Rubia et al., 1999), discriminating between two given durations (Rubia et al., 1999; Smith et al., 2002; Toplak & Tannock, 2005), or generating a few instances of a given interval (Barkley, Murphy, & Bush, 2001; Kerns, McInerney, & Wilde, 2001; Smith et al., 2002). The results of these studies have varied in terms of whether people with ADHD showed timing biases toward shorter intervals, but ADHD timing behavior consistently shows more variability than that of controls. Such a result, however, provides little information about timing mechanisms in ADHD because greater variability is universally found in ADHD cognitive assessment (Castellanos & Tannock, 2002).

What is required here are implicit tests where timing behavior is allowed to emerge as a byproduct of an activity that proceeds without refined judgment and discrimination. There is an implicit aspect of timing behavior that is universally experienced and eminently suitable for psychophysical assessment: the feeling that emerges when we experience rhythm. Such feelings are a prime example of Gestalt; the whole (rhythm) is greater than the sum of the parts (individual time intervals). When we feel rhythm the experience is of the feeling; the actual intervals that create the feeling recede into the background. In this sense the data of interest, the intervals so marked, arise implicitly. We refer to this foreground/background distinction when we inquire if a person is feeling rhythm. Having drawn the distinction, it must be remarked that its relevance to ADHD cognition is not obvious. There are manifestly many musicians who have ADHD; musical or dancing ineptitude is not part of the symptom cluster of ADHD.

That there may be a connection between ADHD and rhythmic expression is suggested by evidence that dopamine pathways are affected in ADHD (Volkow et al., 2007), and that dopamine neurons are tuned to event salience, a key stimulus attribute in the initiation of reward-based learning. Sagvolden et al. (2005) have argued that loss of salience might be functionally expressed by a reward system that is developmentally attuned to shortened delays. At this level of explanation, the symptoms of ADHD (short attention span, hyperactivity, impulsivity) are merely the macroscopic outcomes of steep delay-of-reinforcement gradients. In this article we conjecture that time scale shortening in conditioned learning may have consequences generally for the organization of behavior, and in particular for the repetitive behavior experienced as rhythmic movement.

The production of rhythm is a human capacity about which quite a bit is already known. Practical musical performance mandates the construction of metronomes that reflect true human capacities in timekeeping, and most metronomes have a limiting largo setting at 40 beats per minute (bpm), an interbeat interval of 1.5 seconds. This is practically the slowest setting at which music can be counted. Our conjecture is that rhythmic feeling may be subject to a shorter limiting interval in ADHD. The suggestion is not that people with ADHD cannot feel rhythm, but that there would be no need to build a metronome that extends to 40 bpm if the intended user has ADHD. A smaller pendulum with a shorter maximum period would suffice.

Theoretical Issues in the Assessment of Rhythmic Feel

A recorded drumming performance is literally a succession of marked moments in time: beats. The succession of intervals between beats forms a time series that may be used to assess the feeling of rhythm. Examples of drumming performance displayed as interbeat-interval time series are illustrated in Figure 1. These data were produced by a normal adult (one not diagnosed with ADHD) whose task was simply to produce a steady train of drumbeats at various tempi. In each tempo condition the participant drummed with a synchronizing signal for 16 beats and then continued without the signal for another 60 beats. Most of the pertinent facts about rhythm are deducible from simply noting whether the performances appear stable or whether they wander about. At tempi faster than 40 bpm the performances are manifestly stable; their associated time series seem to have a well-defined mean and variance. Performances at tempi slower than 40 bpm lack this apparent stability, showing a pronounced tendency to meander. Meandering is a specific kind of losing one's way that is characteristic of a random walk process.

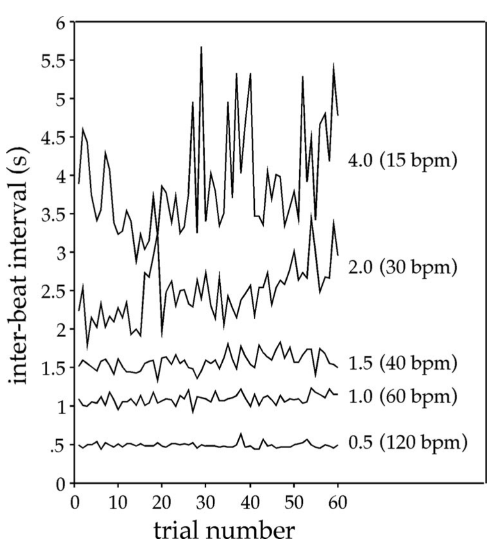

Figure 1. Time series of successive interval estimates are shown for non-synchronized drum beating. Target tempos of 15, 30, 40, 60, and 120 bpm (target time intervals of 4, 2, 1.5, 1, and 0.5 seconds, respectively). Loss of rhythm is implied by wandering estimates at tempo slower than 40 bpm.

Random walks are generated by an imperfect copying mechanism that has the recursive form: $X(t + 1) = \alpha * X(t) + \varepsilon(t)$, where α determines the rate at which successive copies lose their correlation over generations, and ε is the random step that drives the walk to meander. This relation provides an important insight into drumming performances at tempi a little slower than the 40-bpm metronome limit. Consider the options available to a drummer who is asked to perform so slowly that he or she cannot feel the beat. How does such a person know when to strike the drum when the implicit body knowledge, the feel, is missing? One strategy is to use the recollection of the most recent interval as a guide for when it would be judicious to next strike the drum. This strategy naturally generates the recursive pattern observed in the random walk. From the point of view of an observer of drumming performance, inferences about whether somebody else is feeling rhythm comes down to deciding whether the performance indicates the recursive use of explicit memories.

Statistics that are sensitive to recursion are quite different from those that have been typically used to measure timing behavior. Most assessments of the human capacity to produce regular pulses are made at tempi well within the range of rhythmic feel (Allan, 1979; Wearden, 1991), and the sole focus has been on overall accuracy as measured by the coefficient of variation, (standard deviation)/mean. When drumming performance is stable both the mean and standard deviation are well-defined in the sense that they do not themselves change during the performance. In this case, the coefficient of variation is a true measure of relative error. However, in meandering performances the mean drifts, and this makes the interpretation of the coefficient of variation problematic. Assessments made at very slow tempi require statistics that do not assume a stable mean but rather quantify the tendency to drift. Such statistics focus on how well past performance predicts future performance. Meandering performance tends to be less accurate but more predictable than stable performance.

The most common statistic used in psychology to capture predictive accuracy is correlation. In time series analysis the concept of correlation generalizes to the autocorrelation function, the correlation of the series with a copy of itself that has been displaced 1, 2, . . ., k, trials. The autocorrelation function has demonstrated utility in the assessment of rhythmic tapping (Madison, 2001). Related to the autocorrelation function is its Fourier twin, the power spectrum. The power spectrum is especially useful here because it employs trial wavelength rather than trial separation to partition the correlations, and drumming performance is more easily described in terms of wavelength. In the power spectrum global features such as hills and valleys are resolved at the long wavelengths (low frequencies) while the inevitable beat-to-beat variation is resolved at the short wavelengths (high frequencies). Spectral representations are commonly used in the analysis of stable timekeeping (Gilden, Thornton, & Mallon, 1995; Lemoine, Torre, & Delignieres, 2006).

Beyond correlation are statistics that measure nonlinear aspects of prediction. The sample entropy (Richman & Moorman, 2000) is one such statistic that has proven worth as a clinical tool in diagnosing cardiomypathy through wandering heartbeat (Norris, Stein, Cao, & Morris, 2006), and promises to be quite useful in assessing rhythmic feel. The sample entropy measures the tendency for micropatterns in the time series to repeat. Formally, the sample entropy is an average conditional probability; given that X was followed by Y in the past, how likely is it that an event resembling X will be followed by an event resembling Y. Signals that drift generally have lower entropy than signals that fluctuate about a stable mean.

Empirical Assessment of Rhythmic Feel

The following pilot study assessed whether adults with ADHD lose rhythm at *faster* tempo than do normal controls. The study focused on the range of tempo where people typically lose their sense of rhythm and was designed to provoke both stable and wandering behavior in the two groups.

Method

Participants

Eleven adults with a diagnosis of ADHD and 11 adults without ADHD participated in the study, which was approved by the institutional review board. All participants were students at the University of Texas and were between 18 and 30 years of age. The participants with ADHD were referred by the Office for Students with Disabilities. To register with the Office for Students with Disabilities, students must have a *DSM–IV* or ICD diagnosis of ADHD from an external clinician, and they must have received a psychological evaluation in the past 3 years to demonstrate that their assessment is current. All of the participants with ADHD had received a clinical diagnosis, and about half received this diagnosis in childhood. Those who were diagnosed as adults all reported childhood-onset symptoms, as required by *DSM–IV* criteria. The participants with ADHD had not taken any medication in the 24 hours before the study. After complete description of the study to the subjects, written informed consent was obtained.

Materials

A Roland Handsonic percussion controller was used for the collection of data. This device has time resolution comparable to the keyboard but is superior to the keyboard in affording good tactile and auditory feedback. The percussion controller was set to simulate conga drums.

Procedure

Participants each completed three target-tempi conditions of 30, 40, and 60 bpm, corresponding to interbeat intervals of 2, 1.5, and 1 second, respectively. These tempi were chosen to span the critical interval where rhythm breaks down in normal function. In each condition, participants slapped the drum with their dominant hand in time with a synchronizing signal for 16 beats and then continued without the signal for another 3 minutes. To prevent counting, participants drummed while reading aloud from a nontechnical book review printed in large clear type.[1]

Results

Figure 2 displays key statistics at the three target tempi: (A) coefficient of variation, (B) power spectrum in log-log coordinates, (C) serial correlation, and (D) sample entropy.[2] We use the coefficient of variation as a measure of overall accuracy, recognizing that its utility is compromised by drifting performance. The power spectrum (see Thornton and Gilden (2005) for computational method), serial correlation, and entropy are used to characterize drift. It is evident from this figure that the statistics are resolving large group differences in drumming performance at the target tempi. The tempo functions are, however, fairly complex, and the data are best understood by considering the conditions in the order of fastest to slowest tempi, progressing from manifest rhythm to its complete breakdown.

At the fastest tempo, 60 bpm (1-s target), the ADHD and normal control groups have similar performance characteristics. They have similar accuracies, nonlinear predictability (entropy), and low frequency power. As the power at low frequencies picks up the large-scale hill-valley structure, equality between the two groups implies that they have comparable stability in the long run. Where the two groups differ in spectral power is at the high frequencies. Here the normal control group actually shows greater fluctuation magnitude, and this is reflected by the marginally larger coefficient of variation in the normal control group. That the high frequency fluctuations are relatively smaller in the ADHD group makes their performances slightly more predictable in the short run as evidenced by the enhanced serial correlation. The finding that ADHD performance is not in any way compromised at 60 bpm is an important benchmark for our method. If the secondary counting suppression task differentially disrupted drumming performance in the ADHD group it might be expected to enter as a main effect across tempo conditions.

Group differences at 40 bpm are quite large and appear in the three measures of sequential correlation that are sensitive to the loss of rhythmic feel and the onset of random walking. Comparing ADHD

[1] Interval discrimination studies have demonstrated that counting markedly improves performance when durations exceed about 1.2 seconds (Grondin, Mielleur-Wells, & Lachance, 1999). Counting must be prevented in assessments of rhythm at target tempi slower than 60 bpm, if we wish to ensure that performers do not substitute their own counting beat for the intended target. Covert counting is a problem not often encountered in studies of timing behavior as durations exceeding a second are rarely examined. Madison's (2001) work is almost unique in this regard, and he dealt with this problem by simply instructing the participants to not count. Such an instruction places conflicting task demands upon the participant as there is always the implicit requirement in any drumming study that performance be as accurate as possible. An alternative strategy is to suppress counting through a secondary task that requires articulation, one that is highly practiced and relatively automatic. Reading elementary text fits this requirement and is the tactic used in this pilot study.

[2] The sample entropy is a function of two parameters, m - the dimension of the embedding space, and r - the neighborhood size. Here $m = 2$, and $r = .2\sigma$, where σ is the interval standard deviation. These values are typical of practical application (Norris et al., 2006).

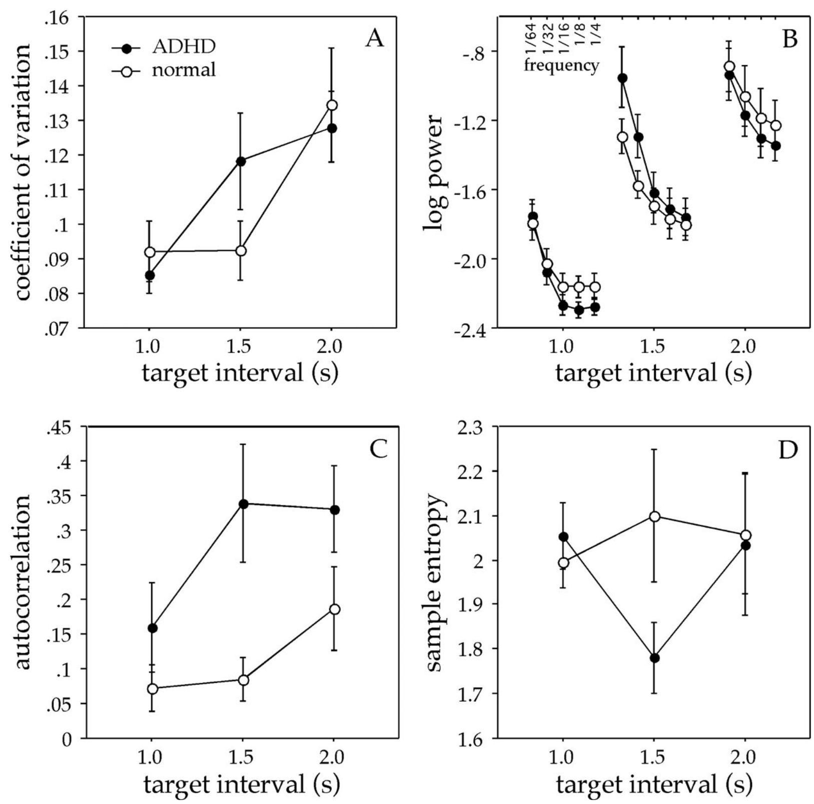

Figure 2. Statistical measures of drumming performances produced by adults with ADHD (filled circles) and by normal controls (open circles). Performance measures are given for the target interbeat intervals 1, 1.5, and 2 seconds, corresponding to tempi of 60, 40, and 30 bpm. (A) Coefficient of variation = standard deviation/mean. (B) Log power as a function of log frequency. (C) Autocorrelation at lag = 1. (D) Sample entropy. Error bars depict standard error of the mean.

with normal control participants, their spectra were steeper, $t(20) = -2.5$, $p < .01$, their entropies were lower, $t(20) = -1.88$, $p < .04$, and their serial correlations were larger, $t(20) = 2.77$, $p < .01$. All three of these statistics suggest that 40 bpm defines a new regime of behavior for the ADHD group, a regime where the sense of rhythm has become so diminished that they substitute replicates of their previous estimates for the target interval. The coefficient of variation in the ADHD group is also quite large at 40 bpm compared to 60 bpm, $t(10) = 2.55$, $p < .02$, providing further evidence that the nature of the performances at the two tempi are quite different. It is equally evident that the normal control group performance is rhythmically stable at 40 bpm, justifying the extension of the metronome to this tempo. On every statistical measure of correlation as well as in the coefficient of variation, the differences between 40 bpm and 60 bpm in the normal control group were small and not significant.

Finally we consider performance beyond the metronome limit, at 30 bpm. In this condition neither group produces competent drumming. The coefficient of variation in both groups is some 50% larger than it was at 60 bpm, a sure sign that rhythmic feeling has been compromised (normal control $t(10) = 4.8$, ADHD $t(10) = 3.2$). Consistent with previous findings (Madison, 2001), the normal control group meanders at 30 bpm: the serial correlations are almost triple that in the two faster conditions ($r = .2$ vs. $r = .08$, $t(31) = 2.0$, $p < .025$). As at 60 bpm, the normal control group is slightly less accurate than the ADHD group, as measured by the coefficient of variation. This difference is due, as it was at 60 bpm, to the fact that the normal control group actually fluctuates a little more wildly from beat to beat. Again, the relative suppression of power at the high frequencies in the ADHD group gives them a larger serial correlation. However, the groups are not distinguished by the sample entropy. Both groups are sufficiently erratic in the short run that even in the presence of strong drift, micropatterns in the time series are poor predictors.

The observation that ADHD performance is both slightly more stable and more accurate than that of the normal controls at the two bounding tempi, 60 and 30 bpm, suggests that the secondary task of reading is not differentially diminishing ADHD performance. If the presence of a secondary task is critical in producing group differences at 40 bpm it must be that the ADHD group is more vulnerable at this tempo. If the ADHD group is more vulnerable to the effects of a secondary task only at 40 bpm it must be that their sense of rhythm is compromised differentially at 40 bpm. As this is essentially the conjecture we seek to test, the secondary task is justified as a reasonable measure to prevent counting.

Discussion

This pilot study of ADHD rhythmic behavior resolves three distinct performance regimes that exemplify two different aspects of working memory. At fast tempo (60 bpm) both ADHD and normal control groups execute accurate and stable performances. The interpretation of this finding is that the system of implicit working memory that produces rhythmic feel has a temporal span that exceeds 1 second in both groups. At rhythmic the metronome limit (40 bpm), this implicit memory system appears to be unavailable to people with ADHD, and their performance reflects a different and more explicit usage of memory, memory of their most recent estimates. As normal controls display rhythmic feel at 40 bpm, this difference implies a difference in the span of rhythmic feel. The effective span of rhythmic feel is apparently contracted in ADHD adults to less than 1.5 seconds. At 30 bpm, both the implicit sense of rhythm and the explicit sense of prior estimates are largely attenuated in both groups. This is presumably why metronomes typically do not offer a setting at 30 bpm. If there is any distinction between the groups at this tempo, it is that the ADHD group has a better sense of what they are doing, as they seem to have a better sense of their most recent estimates. Outside of this observation there is little to distinguish normal control from ADHD performance at 30 bpm.

In this article we have considered one aspect of temporal integration, rhythmic feeling, providing preliminary evidence that this feeling exists over a relatively restricted tempo range in ADHD. Rhythmic feeling is a good place to begin an analysis of the more general issue of temporal integration because it is methodologically simple, it is supported by clear signatures in data, and it involves a system of measurement that does not require sustained vigilance. These preliminary results, however, do not remotely exhaust the range of cognition that is involved in the perceptual organization of temporally based events. Virtually any percept or activity that involves synthesis across time is potentially of interest. In particular, ethological investigation of human actions that imply universal time scales (Schleidt, Eible-Eibesfeldt, & Pöppel, 1987) may be a particularly productive way of investigating ADHD temporality and in understanding what exactly is implied by hyperactivity and inattentiveness.

References

Allan, L. G. (1979). The perception of time. *Perception & Psychophysics, 26,* 340–354.

Barkley, R. A. (1997). Behavioral inhibition, sustained attention, and executive functions: Constructing a unifying theory of ADHD. *Pyschological Bulletin, 121,* 65–94.

Barkley, R. A., Murphy, K. R., & Bush, T. (2001). Time perception and reproduction in young adults with attention deficit hyperactivity disorder. *Neuropsychology, 15,* 351–360.

Castellanos, F. X., Lee, P. P., Sharp, W., Jeffries, N. O., Greenstein, D. K., Clasen, L. S., et al. (2002). Developmental trajectories of brain volume abnormalities in children and adolescents with attention-deficit/hyperactivity disorder. *Journal of the American Medical Association, 288,* 1740–1748.

Castellanos, F. X., Sonuga-Barke, E. J. S., Milham, M. P., & Tannock, R. (2006). Characterizing cognition in ADHD: Beyond executive dysfunction. *Trends in Cognitive Sciences, 10,* 117–123.

Castellanos, F. X., & Tannock, R. (2002). Neuroscience of attention-deficit/hyperactivity disorder: The search for endophenotypes. *Nature Reviews Neuroscience, 3,* 617–628.

Conners, C. K. (1995.) *Conners' Continuous Performance Test*. Toronto, Multi-Health Systems.

Edwards, M. C., Gardner, E. S., Chelonis, J. J., Schulz, E. G., Flake, R. A., & Diaz, P. F. (2007). Estimates of the validity and utility of the Conners' Continuous Performance Test in the assessment of inattentive and/or hyperactive-impulsive behaviors in children. *Journal of Abnormal Child Psychology, 35,* 393–404.

Gilden, D. L., Thornton, T., & Mallon, M. (1995). 1/*f* noise in human cognition. *Science, 267,* 1837–1839.

Grondin, S., Meilleur-Wells, G., & Lachance, R. (1999). When to start explicit counting in a time-intervals discrimination task: A critical point in the timing process of humans. *Journal of Experimental Psychology: Human Perception and Performance, 25,* 993–1004.

Ivry, R. B., & Spencer, R. M. C. (2004). The neural representation of time. *Current Opinion in Neurobiology, 14,* 225–232.

Kerns, K. A., McInerney, R. J., & Wilde, N. J. (2001). Time reproduction, working memory, and behavioral inhibition in children with ADHD. *Child Neuropsychology, 7,* 21–31.

Lemoine, L., Torre, K., & Delignieres, D. (2006). Testing for the presence of 1/f noise in continuation tapping data. *Canadian Journal of Experimental Psychology, 60,* 247–257.

Madison, G. (2001). Variability in isochronous tapping: Higher order dependencies as a function of intertap interval. *Journal of Experimental Psychology: Human Perception and Performance, 27,* 411–422.

Mangels, J. A., Ivry, R. B., & Shimizu, N. (1998). Dissociable contributions of the prefrontal and neocerebellar cortex to time perception. *Cognitive Brain Research, 7,* 15–39.

Norris, P. R., Stein, P. K., Cao, H., & Morris, J. J., Jr. (2006). Heart rate multiscale entropy reflects reduced complexity and mortality in 285 patients with trauma. *Journal of Critical Care, 21,* 343.

Richman, J. S., & Moorman, J. R. (2000). Physiological time-series analysis using approximate entropy and sample entropy. *American Journal of Physiology - Heart and Circulatory Physiology, 278,* 2039–2049.

Rubia, K., Taylor, A., & Taylor, E. (1999). Synchronization, anticipation, and consistency in motor timing of children with dimensionally defined attention deficit hyperactivity behaviour. *Perceptual and Motor Skills, 89,* 1237–1258.

Sagvolden, T., Johansen, E. B., Aase, H., & Russell, V. A. (2005). A dynamic developmental theory of attention-deficit/hyperactivity disorder (ADHD) predominantly hyperactive/impulsive and combined subtypes. *Behavioral Brain Science, 28,* 397–419.

Schleidt, M, Eibl-Eibesfeldt, I., & Pöppel, E. (1987). A universal constant in temporal-segmentation of human short-term behavior. *Naturwissenschaften, 74,* 289–290.

Smith, A., Taylor, E., Lidzba, K., & Rubia, K. (2003). A right hemispheric frontocerebellar network for time discrimination of several hundreds of milliseconds. *Neuroimage, 20,* 344–350.

Smith, A., Taylor, E., Rogers, J. W., Newman, S., & Rubia, K. (2002). Evidence for a pure time perception deficit in children with ADHD. *Journal of Child Psychology and Psychiatry, 43,* 529–542.

Sonuga-Barke, E. J. S., Saxton, T., & Hall, M. (1998). The role of interval underestimation in hyperactive children's failure to suppress responses over time. *Behavioural Brain Research, 94,* 45–50.

Thornton, T. L., & Gilden, D. L. (2005). Provenance of correlations in psychological data. *Psychonomic Bulletin and Review, 12,* 409–441.

Toplak, M. E., & Tannock, R. (2005). Time perception: Modality and duration effects in attention-deficit/hyperactivity disorder (ADHD). *Journal of Abnormal Child Psychology, 33,* 639–654.

Valera, E. M., Faraone, S. V., Murray, K. E., & Seidman, L. J. (2007). Meta-analysis of structural imaging findings in attention-deficit/hyperactivity disorder. *Biological Psychiatry, 61,* 1361–1369.

Volkow, N. D., Wang, G.-J., Newcorn, J., Telang, F., Solanto, M. V., Fowler, F. S., et al. (2007). Depressed dopamine activity in caudate and preliminary evidence of limbic involvement in adults with attention-deficit/hyperactivity disorder. *Archives of General Psychiatry, 64,* 932–940.

Wearden, J. H. (1991). Do humans possess an internal clock with scalar-timing? *Learning and Motivation, 22,* 59–83.

Received July 18, 2008
Revision received October 15, 2008
Accepted October 27, 2008 ■