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Cognitive–Neuropsychological Function in Chronic Physical Aggression and Hyperactivity

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Abstract

Histories of violence and of hyperactivity are both characterized by poor cognitive–neuropsychological function. However, researchers do not know whether these histories combine in additive or interactive ways. The authors tested 303 male young adults from a community sample whose trajectories of teacher-rated physical aggression and motoric hyperactivity from kindergarten to age 15 were well defined. No significant interaction was found. In a 1st model, both histories of problem behavior were independently associated with cognitive–neuropsychological function in most domains. In a 2nd model controlling for IQ, general memory, and test motivation, the 3 working-memory tests (relevant to executive function) remained associated with physical aggression, and 1 remained associated with hyperactivity. These results support an additive model.

Most children who show elevated levels of physical aggression in preschool or kindergarten typically show important reductions of those behaviors over time (Bongers, Koot, van der Ende, & Verhulst, 2003; Tremblay et al., 1996, 1999). However, a significant subset of these children shows comparatively high levels of these problem behaviors throughout childhood and well into adolescence (Nagin & Tremblay, 1999), and such elevation specifically among aggressive male individuals predicts violence in late adolescence (Broidy et al., 2003). One set of risk factors that appears to distinguish chronic elevated levels of these problem behaviors from other developmental trajectories is relatively poor cognitive–neuropsychological function (Moffitt, Lynam, & Silva, 1994). However, impaired cognitive–neuropsychological function has also been reported in studies of attention deficit hyperactivity disorder (ADHD; Sergeant, Geurts, Huijbregts, Scheres, & Oosterlaan, 2003). Further, poor neuropsychological function has been linked to early onset of both aggression

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and hyperactivity-related problems (Moffitt et al., 1994). Unfortunately, many cognitive–neuropsychological studies of hyperactivity still have not examined concurrent aggression (Nigg, 2001), and studies of aggression do not always consider the relevance of hyperactivity (Pennington & Ozonoff, 1996). Thus, relevance of cognitive–neuropsychological characteristics to physical aggression, hyperactivity, and the combination of physical aggression and hyperactivity requires further clarification (Raine, 2002).

Several reviews have already addressed inconsistencies in studies of the neuropsychological bases of physical aggression (Moffitt, 1990; Morgan & Lilienfeld, 2000) and hyperactivity (Pennington, Bennetto, McAleer, & Roberts, 1996). Such studies have examined physical aggression and hyperactivity in clinical populations as part of conduct disorder (CD) or ADHD or in community samples as part of conduct problems (CP) and hyperactivity-impulsivity-attention (HIA). Efforts to address these inconsistencies suggest that poor cognitive–neuropsychological function in ADHD and CD has been most reliably identified when the focus was on the cognitive–neuropsychological functions associated with executive function (Nigg, 2001; Pennington et al., 1996; Sergeant, Geurts, & Oosterlaan, 2002). From a cognitive perspective, executive function can be defined in terms of its outcome, which is deliberate problem solving (Séguin & Zelazo, 2004; Zelazo, Müller, Frye, & Marcovitch, 2003). One important set of processes involved in executive function is working memory. Working memory refers to an “on-line” or “in-real-time” set of cognitive processes involved in the various phases of problem solving. For example, working memory allows an individual to shift perspectives on a problem, define goals while considering several parameters of a problem simultaneously, plan a strategy while anticipating consequences, execute steps of a plan held in memory, monitor progress, detect and correct errors, and accommodate new data while filtering out interference. From a neuropsychological perspective, these abilities appear to be subsumed largely but not exclusively by the dorsolateral frontal cortex. Poor cognitive–neuropsychological function in general and poor executive function in particular have also been most reliably identified within CD and CP when the focus has been on key symptoms such as physical aggression (Giancola, Mezzich, & Tarter, 1998; Séguin, Boulerice, Harden, Tremblay, & Pihl, 1999) or within ADHD when there was presence of hyperactive–impulsive behaviors (Barkley, 1997; Houghton et al., 1999), even in nonclinical populations (Séguin, Arseneault, Boulerice, Harden, & Tremblay, 2002) as well as in girls (Hinshaw, Carte, Sami, Treuting, & Zupan, 2002). The ADHD hyperactive–impulsive subtype has also been found to perform more poorly in “executive inhibition” (Nigg, 2001) and planning (Nigg, Blaskey, Huang-Pollock, & Rappley, 2002) than on other measures of executive function.

Studies of executive function in these externalizing behavior problems have typically focused on either ADHD or CD, although some studies of externalizing problems have selected participants on the basis of CD and ADHD (Oosterlaan, Logan, & Sergeant, 1997). When comorbidity between CD and ADHD was examined, one diagnosis was typically used to control for the other (Giancola et al., 1998; Toupin, Déry, Pauzé, Mercier, & Fortin, 2000). Those studies suggest that executive function in general (Toupin et al., 2000) and working memory in particular (e.g., Giancola et al., 1998) are poor in individuals with a history of physical aggression regardless of ADHD. In a series of studies, we first found that among many neuropsychological domains, stable and unstable physically aggressive boys, defined as “fights with other children,” “kicks, bites and hits other children,” and “bullies or intimidates other children,” showed poorest performance in executive function abilities at ages 13 and 14 years even after the studies controlled for the other cognitive–neuropsychological domains, such as verbal and spatial learning (Séguin, Pihl, Harden, Tremblay, & Boulerice, 1995). However, Pennington and Ozonoff (1996) appropriately questioned whether ADHD or IQ could account for our findings. To test this hypothesis in a follow-up study, we focused on working memory, the most sensitive and neuropsychologically valid component of our executive function abilities, gathered diagnostic information on ADHD, and administered additional IQ tests to the same sample of boys at 15 and 16 years. Our initial findings were supported despite the fact that the study controlled for both ADHD and IQ (Séguin et al., 1999). Of note, we also failed to find any association between working memory and ADHD. In an additional study, we focused on response perseveration using Newman and colleagues’ (Newman, Patterson, & Kosson, 1987) adaptation of a Card Playing Task (Siegel, 1978). We found an attenuating effect of teacher-rated motoric hyperactivity. We surmised that teacher-rated motoric hyperactivity, defined by items such as “restless, runs about, or jumps up and down” and “does not keep still, squirmy, fidgety,” might have been a more sensitive and conservative covariate to physical aggression than the broader construct of ADHD as measured in our previous study and which includes inattention and impulsivity problems (Séguin et al., 1999).

In these earlier designs, none of our studies had selected participants on both behavior problems from the outset. Consequently, we have gained knowledge about the cognitive–neuropsychological aspects of physical aggression independent of ADHD or motoric hyperactivity, but we know little about the cognitive–neuropsychological aspects of ADHD or motoric hyper-activity independently from physical aggression. In a related matter, we do not know whether the comorbidity between physical aggression and motoric hyperactivity is additive or interactive. In a broader sense, this question asks whether CP–HIA is different from the addition of CP to HIA (Waschbusch, 2002).

To date, studies of cognitive–neuropsychological function in CP and HIA in community samples appear to be consistent with an additive model. In other words, those individuals who show the comorbid condition show the worse performance, followed by those who show one or the other condition (Lynam, 1998; Moffitt & Henry, 1989; Moffitt & Silva, 1988). However, like in most studies of this type, Moffitt and colleagues (Moffitt & Henry, 1989; Moffitt & Silva, 1988) and Lynam (1998) contrasted groups in a single-factor design. This has been a common practice among the studies that have used a four-grouping category system to study the relation of CP and HIA on a variety of characteristics, as only 25% of them used a two-factor design and tested for main effects and interactions (Waschbusch, 2002). Both strategies have their merits; however, a factorial design will tell researchers about (a) the relative contribution each dimension brings to the outcome and (b) whether this worse performance is the result of an additive or interactive effect.

A closer examination of data from community sample studies suggests limitations to a straightforward additive hypothesis. For example, in Lynam’s (1998) study, it is unclear whether the significant difference on the Trail Making Test (Forms A and B combined—

easy and difficult measures, respectively, of concentration and flexibility) tested in a one-factor model could have been a main effect of HIA only or an interaction of CP and HIA, instead of an additive effect had it been tested in a two-factor model. Similarly, in Moffitt and colleagues' (Moffitt & Henry, 1989; Moffitt & Silva, 1988) studies of executive function using a one-factor model, there might also have been a main effect of HIA on the Mazes subtest (a measure of planning) of the Wechsler Intelligence Scales for Children—Revised and an interactive effect on the Trail Making Test, Form B, had the analyses been conducted with a two-factor model (see Moffitt & Henry, 1989, Table 2, p. 114). Only the Rey Osterreith Copy Accuracy score appeared to show an additive effect in that study. Reanalyses of data using a two-factor model from studies that have four groups would help answer these questions, at least partially (Waschbusch, 2002). For example, Lynam recently applied a two-factor design to his data originally published in 1998 using a one-factor model. Although he failed to find an interactive effect on the Trail Making Test as suggested above, he did find an interaction on the Card Playing Task (D. R. Lynam, personal communication, July 17, 2002), a measure that involves cognitive and emotional regulation.

Nigg (2001) noted that control for IQ is notoriously absent from most studies in which it could be considered. A recent meta-analysis indicates that performance and verbal IQ are poorest in those children with comorbid HIA and CP relative to control children, but close examination of those studies that provided either performance, verbal, or both IQ scores for all four subgroups suggests that there may have been a main effect of HIA on performance IQ and an HIA × CP interaction for verbal IQ—although Waschbusch (2002) did not necessarily draw that conclusion explicitly. It is therefore particularly important to control for IQ because IQ tests most likely measure nonexecutive components that may be necessary for executive function (Pennington et al., 1996).

Although we have used history of problem behavior in our earlier studies (reviewed above), assignment to groups is typically done on a threshold basis (i.e., by fitting a percentile cutoff on a scale or by meeting a criterion number of symptoms). Whether a case is close to that threshold is rarely taken into account, and variations around the threshold could be related to executive function. The trajectory methodology uses all available developmental data points and assigns individuals to categories on the basis of a posterior probability rule. Resulting groups are meant to represent approximations of an underlying continuous process (Nagin & Tremblay, 1999, 2001).

The current study was thus designed to examine cognitive–neuropsychological function in male young adults when trajectories of physical aggression and of motoric hyperactivity are combined together in a two-factor model. We expected worse cognitive–neuropsychological function in the trajectory with highest probability of having both physical aggression and hyperactivity histories, as suggested by the work of Lynam (1998; Houghton et al., 1999) and Moffitt and colleagues (Moffitt & Henry, 1989; Moffitt & Silva, 1988). However, we did not know if worse cognitive–neuropsychological function might come from the additive or interactive combination of physical aggression and motoric hyperactivity. We also sought to examine whether the expected working memory deficits could not be accounted for by IQ and nonexecutive cognitive abilities.

Method

Participants

At age 20 years (range = 18.47–22.02), 303 young men were selected from a longitudinal study of a French-speaking community sample attending schools from disadvantaged areas of Montréal when first assessed at age 6. Teachers assessed these boys' physical aggressive behavior and hyperactivity seven times—first at age 6, then yearly at ages 10–15 years with the Teacher Form of a French-Canadian version of the Social Behavior Questionnaire (SBQ; Tremblay, Desmarais-Gervais, Gagnon, & Charlebois, 1987). The main scales of interest were those assessing physically aggressive behavior and hyperactivity. Three items composing the Physical Aggression scale were 1 (*fights with other children*), 2 (*kicks, bites and hits other children*), and 3 (*bullies or intimidates other children*). The items assessing hyperactivity were 1 (*restless, runs about, or jumps up and down*) and 2 (*does not keep still, squirmy, fidgety*). Items were rated each year on the following scale: 0 (*never*), 1 (*sometimes*), or 2 (*often*). Internal consistency (Cronbach's alpha) over assessments ranged from 0.78 to 0.87 ($M = 0.84$) for the Physical Aggression scale and from 0.85 to 0.89 ($M = 0.86$) for the Hyperactivity scale (Nagin & Tremblay, 1999). Participants were treated in accordance with American Psychological Association (2002) ethical guidelines and guidelines of the Louis-Hyppolyte Lafontaine Hospital ethics committee.

Assignment to trajectories—Scores from the seven assessment points were analyzed using a formal statistical method designed to identify distinctive behavioral trajectories across assessment points (Nagin, 1999). Four trajectories for physical aggression and four for hyperactivity were identified in a previous publication using the entire sample of the longitudinal study ($N = 1{,}037$; Nagin & Tremblay, 1999). The patterns of behavior across time were also very similar for both physical aggression and hyperactivity and received the following labels: (a) one trajectory was found to be consistently high across time (*chronic*); (b) a second trajectory began with high rates of the behavior, which subsequently declined over time (*high-level "desister"*); (c) a third trajectory began with moderate-low rates, which also declined over time (*low-level desister*); and (d) a fourth trajectory showed very low rates at all time points (*never*). Finally, there was no trajectory showing an increase over time in this sample, although this has been observed in other samples (Broidy et al., 2003).

A key output of model estimation is the posterior probability of group membership. For each trajectory group, this probability measures the likelihood of an individual belonging to that trajectory group on the basis of observations across assessments. In other words, 100% accuracy in classification is not assumed nor required. For example, in the case of an individual who scores high on hyperactivity at all assessment periods, the posterior probability of membership to the chronic group would be high, whereas the probability of membership to the low trajectory group would be near 0. Participants can be assigned to the trajectory group for which they show the highest probability of belonging. Ideally, the posterior membership probability should be near 1 for this trajectory group. In the current analysis, the average posterior probability for the assigned trajectory group was always greater than .73 and generally greater than .80. Thus, we conclude that the model fits the data well. Posterior probabilities will, in turn, allow weighting of the data and correction for that assignment rule in analyses involving trajectory comparisons. Nagin and Tremblay (1999) noted that, although distinct, the trajectories of hyperactivity and physical aggression were highly related (ordinal by ordinal Spearman $r = .60$, $p < .001$). In contrast, within-year correlations between the Physical Aggression and Hyperactivity scales were $r = .61$, $r = .52$, $r = .46$, $r = .47$, $r = .42$, $r = .43$, and $r = .40$ for ages 6, 10, 11, 12, 13, 14, and 15 years, respectively.

Examination of the four physical aggression trajectories crossed with the four hyperactivity trajectories from the Nagin and Tremblay (1999) analyses (see Total Sample column in Table 1) shows the overlap between the physical aggression and hyperactivity trajectories. Thus, the likelihood of being *chronic* in one domain and *never* in the other was extremely low. Because our goal was to test hypotheses of the joint effects of physical aggression and hyperactivity trajectories, we decided a priori to group the two high and the two low trajectories within each domain on the basis of Nagin and Tremblay's (1999) work. We have therefore split the behavioral domains into dichotomous categories: *never and low* vs. *high and chronic*. These will be respectively relabeled *low* and *high* for convenience. Thus, from a 4 × 4 design that contained off-diagonal cells with very few participants, we moved to a 2 × 2 (Physical Aggression × Hyperactivity) design. This would allow us to compare individuals with lower vs. higher levels of physical aggression and hyperactivity.

Laboratory sample selection procedure—For this study, our laboratory sample was selected from a larger sample of 1,037 male young adults. In order to have sufficient power for testing hypotheses (i.e., $1 - \beta = 0.95$ at α level .05 for detecting a small effect size of about 0.10; Cohen, 1988; Erdfelder, Faul, & Buchner, 1996), we had estimated a priori a need for approximately 300 participants. Within the sample of 1,037, we attempted to contact 494 participants over a period of 18 months until we met our sample size objective and obtained consent to participate from 304 male young adults. One participant violated drug/alcohol abstinence restrictions and could not be rescheduled. He was removed from the laboratory sample. The final laboratory sample thus comprised 303 participants.[1] The sampling strategy resulted in a similar magnitude of association between both behavior trajectories (ordinal by ordinal Spearman $r = .64$, $p < .0001$) found in the total sample. Table 1 shows the distribution for the laboratory sample unweighted and weighted by posterior probabilities prior to creating the dichotomous categories used in the analyses. The effect of the assignment rule on the resulting laboratory sample, which is based on the joint probabilities of physical aggression and hyperactivity, can be seen by comparing the nonweighted and weighted columns within each sample of Table 1. The laboratory sample was compared with the remainder of the total sample on several indices. No differences were found on yearly self-reports of delinquency at the ages of 11–17 years nor on the Diagnostic Interview Schedule for Children (DISC) CD or ADHD number of symptoms or diagnoses. We therefore conclude that the current laboratory sample represents well the total sample on these measures.

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[1] Of the 190 participants that we attempted to contact but who did not come to the laboratory during that time, 53 could not be traced, 24 could not be scheduled for various reasons (e.g., interested but could not find time to come, lived at a great distance), 50 failed to show up despite our best scheduling efforts, 44 declined to participate at first contact, we cancelled 15 scheduled visits as quotas for specific criteria were attained, 3 participants were in prison, and 1 had died.

Relation of physical aggression and hyperactivity trajectories to CD and ADHD—To more fully describe how trajectories of physical aggression and hyperactivity relate to the diagnoses of CD and ADHD, we examined the proportion of boys who obtained such diagnoses between 14 and 16 years of age on a French adaptation of the DISC (Version 2.25, child [DISC–C] or parent [DISC–P] versions; Breton et al., 1999; Breton, Bergeron, Valla, Berthiaume, & St-Georges, 1998; Costello, Edelbrock, & Costello, 1985) as a function of trajectories. The DISC 2.25 diagnoses were based on the *Diagnostic and Statistical Manual of Mental Disorders* (3rd ed.; *DSM–III–R*; American Psychiatric Association, 1987). CD and ADHD classification was available for 756 and 749 boys, respectively. Results using a combination of the child and parent forms indicate that 5% of that sample met criteria for CD and 6.7% met criteria for ADHD. In the analysis for CD, 67% of all cases were on the high trajectory of physical aggression. In the analysis for ADHD, 72% of cases were in the high trajectory of hyperactivity. The greatest percentages of CD (51%) or ADHD (55%) diagnoses were found in the combined trajectories of high physical aggression and high hyperactivity. Further, 63% of the cases ($n = 23$) with both CD and ADHD diagnoses were found in the combined trajectories of high physical aggression and high hyperactivity.

Cognitive–Neuropsychological Measures

Verbal and performance IQ estimates were obtained with the Vocabulary and Block Design subscales, respectively, of the Épreuve Individuelle d'Habileté Mentale (translation: Individual Tasks of Mental Ability; Chevrier, 1989). These are French equivalents of the Vocabulary and Block Design subtests of the Wechsler Adult Intelligence Scale (Wechsler, 1981). We found that performance on these subscales correlated highly with French versions of the Wechsler Intelligence Scale for Children—Revised (Séguin et al., 1999; Wechsler, 1974) that were administered about 5 years earlier, at age 15, to a subgroup of boys present in the current sample ($n = 110$, Vocabulary $r = .69$, $p < .001$; Block Design $r = .71$, $p < .001$). General memory functions (operationalized here as those functions often associated with the hippocampus and medial temporal lobe) were assessed with Paired Associate Learning and Digit Span subtests of the Wechsler Memory Scales—Revised (Wechsler, 1987). The model developed by Milner and Petrides postulates that impairments in general memory will necessarily affect executive function (Petrides & Milner, 1982), at least in individuals with lesions. This neuropsychological issue can be formulated in two ways: (a) prefrontal functions are affected by brain changes in regions outside but closely connected to the prefrontal cortex (Petrides, 1995) and (b) nonexecutive components are involved in executive function tasks (Pennington et al., 1996). Therefore, general memory abilities will be used to control for working memory performance. Working memory is operationalized here with two validated middorsolateral frontal lobe tasks (i.e., Number Randomization and Self-Ordered Pointing; Petrides, Alivisatos, Meyer, & Evans, 1993) and two validated posterior–dorsolateral tasks (Spatial and Non-Spatial Conditional Association tasks; Petrides, 1985; 1990). The Self-Ordered Pointing and Conditional Association tests were administered in computerized form (Peterson, Pihl, Higgins, & Lee, 1997), which differ from the noncomputerized versions. Scoring accuracy is increased, experimental error is reduced for the Conditional Association tasks, and the Self-Ordered Pointing abstract form has a greater degree of interference due to redundancy in abstract design features across stimuli. A factor analysis at ages 13 and 14 of a neuropsychological test battery including the tests of general and working memory proposed herein supported the theoretical distinction between general and working memory (Séguin et al., 1995).

Task-instructions summary and dependent variables—The Vocabulary subtest of the Épreuve Individuelle d'Habileté Mentale requires respondents to define words of gradually increasing difficulty, whereas the Block Design subtest requires the reproduction of two-dimensional patterns of red and white colors with 4 or 9 red and white blocks (Chevrier, 1989). The dependent variable for Vocabulary consists of number of words correctly defined, with answers counting for 1 or 2 points depending on the quality of definition provided. The score for Block Design consists of number of problems solved, and each problem is scored as a function of time to reach the solution. The Digit Span task requires repeating digits in increasing spans in forward and backward orders (score is total number of problems solved), whereas the Paired Associates Learning task requires listening to easy or difficult word pairs (score is total number of correct pairs). The first word of the pair is then provided to cue recall for the second word (Wechsler, 1987). In the Number Randomization task, a range of numbers is provided (e.g., from 1 to 10; Séguin et al., 1995, 1999, 2002). All numbers in the range must then be selected without using repetition, showing an apparent pattern, repeating a digit twice, or using more than two consecutive numbers. Ranges used were of 4, 6, 8, 10, and 12 digits, with two trials at each level. The dependent variable was number of successful trials until two consecutive failures at one level. The Self-Ordered Pointing consists of two sets (one abstract and one concrete) of 12 arrays of the same 12 stimuli (Milner, Petrides, & Smith, 1985). The positions of the stimuli change from one array to the next, and one must select a new stimulus in each array. Repetitions of an already chosen stimulus are counted as errors. Each set is presented three consecutive times. Total number of errors is used as the dependent variable. Both Conditional Association tests require inductive reasoning in order to uncover predetermined patterns of association between a button and a light (Spatial version) and a color and an abstract symbol (Non-Spatial version). Participants have six chances per trial to find the correct association rule for that trial. The task is completed after 18 consecutive successful trials or when a maximum of 180 trials is reached. Total number of trials with errors is used as the dependent variable. Because we used the score from the first of the two tasks performed (where applicable), the current score is made of either Spatial or Non-Spatial errors (see details below).

Test order—For most participants (n = 188), all tasks were administered in two blocks separated by a break as part of a battery of cognitive and personality tests (not all relevant to the present study). For a subset of participants (n = 115), these blocks were administered in two visits for logistic purposes independent from this study. This subset of participants differed from the other subset only in the fact that the Spatial Conditional Association task was administered in addition to the Non-Spatial Conditional Association task common to all participants. We compared average number of errors for the first of the Conditional Association tasks administered and found no differences between the two participant subsets, $t(297) = 1.41$, *ns*. We have therefore created one single score for Conditional

Association tasks. Means, standard deviations, and ranges for cognitive tests are presented in Table 2.

Test motivation—In the absence of direct observations during task performance, self-report test motivation data were collected at the end of each block when participants were asked three questions: (a) "To what extent did you feel motivated to participate in the tasks you just completed?" (b) "To what extent did you feel involved in the tasks you completed?" and (c) "To what extent did you make an effort to complete the tasks as best you could?" Each question was rated on a 7-point scale ranging from *not at all* (1) to *strongly* (7). Motivation scores were combined into a single scale with a reliability alpha of 0.86.

Results

Preliminary Analyses

Missing data were minimal.[2] All cognitive variables were entered in standardized form for ease of comparison. Confounding variables were then ruled out as follows:

1. There were no effects for completing the test battery in one or two visits.
2. There were no effects of block order on performance.
3. There were no block main effects on test motivation
4. There were no effects of age at testing on performance.

Correlations among cognitive measures and the motivation index are shown in Table 3. Because of unequal *N*s in our groups, we have chosen to test hypotheses using general linear model (GLM) analysis of variance (ANOVA) using PROC GLM in SAS (Version 8.2; SAS Institute, 2001) with weighted data. When data are weighted, each participant is represented in each cell as a function of his probability of being assigned to that cell. This preserves the continuous nature of the classification variable. Because weights sum to 1, the total analysis remains with $N = 303$. Relevant assumptions were satisfied for each analysis after appropriate transformations and corrections were made (Tabachnick & Fidell, 2001).

Analyses (not shown in tables) performed separately using one-factor designs on the initial four trajectories within physical aggression and within hyperactivity support the strategy of grouping the two high and two low trajectories together (even after controlling for test motivation). Briefly and specifically, the overall multivariate ANOVA (MANOVA) for physical aggression was found to be significant, Pillai's trace = 0.31, approximate $F(21, 2445) = 13.44$, $p < .0001$.[3] The effect of physical aggression groups was also significant on all cognitive variables. The standardized mean differences between the *never* and *chronic* groups on working-memory tasks were 0.66 for Number Randomization, 1.52 for Self-Ordered Pointing, and 1.12 for Conditional Association. These mean standard differences represent large effects on average (Cohen, 1992). The overall MANOVA for hyperactivity

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[2] There were only 11 participants with missing data, which affected no more than two tests and which was not related to participant characteristics. These missing data for each variable are reflected in the number of participants presented in Table 2. Because participants had completed substantial portions of the cognitive–neuropsychological battery, missing data were replaced by the relevant Aggression × Hyperactivity trajectory cell mean for greater accuracy of estimation.

[3] Pillai's trace can be interpreted also as a multivariate R^2 or η^2 (Erdfelder et al., 1996).

was also found to be significant, Pillai's trace = .20, approximate $F(21, 2811) = 9.77$, $p < .0001$. The effect of hyperactivity groups was also significant on all cognitive variables. However, although the highest scores were found in the never hyperactive trajectory, the lowest scores for all tests with the exception of Vocabulary were found in the high desister trajectory, although this trajectory did not differ significantly from the chronic hyperactivity trajectory. Thus, the standardized mean differences between the extreme groups on working memory tasks were 0.34 for Number Randomization, 0.81 for Self-Ordered Pointing, and 0.60 for Conditional Association (all averaging a medium effect size) but was greatest for Vocabulary (1.01; a large effect size). For both physical aggression and hyperactivity, the most sensitive contrasts between adjacent groups ordered from *never* to *chronic* were found between the moderate desister and low desister groups. Within physical aggression and hyperactivity, respectively, the *never* and *low desister* groups were joined together to form the *low trajectory group*, whereas the *moderate desister* and *chronic* groups were joined together to form the *high trajectory group*. We then used the 2 × 2 design to test if poor cognitive–neuropsychological function in working memory in particular were related to (a) physical aggression trajectories, (b) hyperactivity trajectories, (c) or their combination.

Effects of Physical Aggression and Hyperactivity

Prior to examining hypotheses with control for test motivation, we examined the effects of physical aggression and hyperactivity on test motivation itself. There was no effect of physical aggression. However, and as test-motivation marginal means in Tables 4 and 5 suggest, we found a main effect for hyperactivity—global $F(3, 1159) = 12.89$, $p < .0001$—and a univariate hyperactivity effect, $F(1, 1159) = 20.50$, $p < .0001$, partial $\eta^2 = 0.017$. Although the test-motivation cell means shown in Table 5 suggest an interaction, the effect only approached significance, $F(1, 1159)$, $p = .06$, partial $\eta^2 < 0.003$. Because test motivation was related both to hyperactivity and to three cognitive tests (see Table 2), all further analyses were run with a control for test motivation. The homogeneity of regression-slopes assumption for motivation and cognitive variables within cells was always met.

We then tested two models as follows. The first model examined the relation of cognitive–neuropsychological variables to the combined physical aggression and hyperactivity trajectories. The multivariate interaction between physical aggression and hyperactivity effect was not significant: Pillai's trace = .009, exact $F(7, 1152) = 1.60$, $p = .13$. The multivariate physical aggression effect was significant: Pillai's trace = .13, exact $F(7, 1152) = 24.65$, $p < .0001$. The multivariate hyperactivity effect was also significant: Pillai's trace = .04, exact $F(7, 1152) = 7.14$, $p < .0001$. Finally, the multivariate effect of test motivation was significant: Pillai's trace = .029, exact $F(7, 1152) = 4.96$, $p < .0001$. Using a threshold of $\alpha < .05$, Table 6 shows that the effect of physical aggression groups was significant on all cognitive variables, the effect of hyperactivity was significant only on Paired Associates Learning, Digit Span, and Self-Ordered Pointing, and test motivation had effects only on Block Design, Digit Span, and Conditional Association. Table 6 also shows that, at best, the nonsignificant interactions would have accounted for 0.3% of the variance for Vocabulary and Conditional Association. Otherwise, most of these significant tests of main effects would still meet a more conservative criterion of $p < .007$ using Bonferroni correction for physical aggression, but only Paired Associates would meet this strict criterion for hyperactivity. This analysis supports an additive model of physical aggression and hyperactivity with respect to most cognitive–neuropsychological variables included here.

The second model tested whether working memory (i.e., Number Randomization, Self-Ordered Pointing, and Conditional Association) remained significantly related to trajectories after controlling for the other nonexecutive cognitive–neuropsychological variables, that is, an estimate of IQ (Vocabulary and Block Design) and general memory (Paired Associates Learning and Digit Span). All the effects were significant except the interaction between physical aggression and hyperactivity and the effect of test motivation (see Table 7). The univariate effects of trajectories and cognitive covariates are presented in Table 8. Marginal adjusted means (i.e., least squares means) and standard errors for the physical aggression effect on the standardized Number Randomization score for low and high physical aggression were 0.11 ($SE = 0.04$) and −0.12 ($SE = 0.05$), respectively, and for low and high hyperactivity were −0.03 ($SE = 0.05$) and −0.06 ($SE = 0.03$), respectively. Marginal adjusted means and standard errors for the physical aggression effect on the standardized Self-Ordered Pointing score for low and high physical aggression were 0.09 ($SE = 0.04$) and −0.17 ($SE = 0.05$), respectively, and for low and high hyperactivity were 0.04 ($SE = 0.04$) and −0.12 ($SE = 0.04$), respectively. Marginal adjusted means and standard errors for the physical aggression effect on the standardized Conditional Association score for low and high physical aggression were 0.07 ($SE = 0.04$) and −0.16 ($SE = 0.05$), respectively, and for low and high hyperactivity were −0.03 ($SE = 0.05$) and −0.06 ($SE = 0.05$), respectively. This final analysis indicated that all three working-memory tests remained significantly related to a history of physical aggression although the relationship was considerably attenuated by the covariates and only the effect of hyperactivity on Self-Ordered Pointing remained clearly additive when physical aggression and covariates were considered simultaneously.

Discussion

This study shows in a first model that histories of elevated levels of physical aggression *or* of motoric hyperactivity in male young adults from a community sample were independently associated with poor cognitive–neuropsychological function except for two performance tasks representing performance IQ and one test of working memory (i.e., Conditional Association), which were only related significantly to physical aggression. More specifically, and for all other tasks, the study did not reveal any significant interaction and therefore shows that the addition of physical aggression *and* hyperactivity histories yields the worse cognitive–neuropsychological performance. Further, once we controlled for nonexecutive cognitive–neuropsychological factors in a second model that simultaneously takes into account histories of physical aggression and of hyperactivity, all three working memory scores, representing basic abilities relevant to executive function, remained significantly related to history of physical aggression, and the Self-Ordered Pointing score remained also significantly and independently related to history of hyperactivity. Thus, not only the relation of physical aggression and hyperactivity to working memory cannot be accounted for by the more general neuropsychological impairment, but this additional control reveals an unambiguous additive relation of physical aggression and hyperactivity on Self-Ordered Pointing performance. These results are all the more interesting because trajectories of physical aggression and hyperactivity were highly correlated.

Relevance of Physical Aggression and Hyperactivity to Neuropsychological Function

The questions of relevance of neuropsychological function to physical aggression or hyperactivity and to comorbid physical aggression and hyperactivity have been around for some time as part of studies of CD and ADHD (Pennington et al., 1996) as well as antisocial conduct (Raine, 2002). Although we had in previous studies examined the effect of motoric hyperactivity or ADHD in samples selected for physical aggression, we had never examined motoric hyperactivity in its own right. In a first study of a sample selected for history of physical aggression, mother- or child-rated DISC diagnoses of ADHD were related to nonexecutive abilities but not to working memory (Séguin et al., 1999). A narrower focus on motoric hyperactivity items instead of the entire construct of ADHD proved to be the more sensitive alternative (Séguin et al., 2002). Thus, our results are particularly consistent with several clinical studies that have examined neuropsychological function where physical aggression is a salient feature of CD (Giancola et al., 1998; Séguin et al., 1999) and in studies where hyperactivity is a salient feature of ADHD (Barkley, 1997; Milich, Balentine, & Lynam, 2001; Nigg, 2001; Nigg et al., 2002). At a descriptive level, physical aggression showed more important effects on test performance than hyperactivity as measured by the F, R^2, and partial η^2 statistics. For example, physical aggression accounted for 2%–8% of the variance in individual cognitive–neuropsychological tests used in this study in our first model, whereas motoric hyperactivity only accounted for less than 0.1% to a maximum of 3% of the variance. Nonetheless, the key contribution of our study is our finding of independent relations of physical aggression and hyperactivity with cognitive neuropsychological function in general and with working memory in particular with the use of a factorial design.

Specificity of Working Memory Problems

In examining the differential effects of physical aggression and motoric hyperactivity on working memory, we may have selected tests that were more sensitive to physical aggression than to motoric hyperactivity and therefore underestimated the specific working memory impairments related to motoric hyperactivity. Our working memory tests were largely nonverbal, although Number Randomization requires a verbal response and Self-Ordered Pointing—Concrete may rely heavily on verbal working memory because it uses representational drawings that can be easily coded and retrieved through verbal strategies. In this study, we again examined these working memory tests, only one of which (i.e., Self-Ordered Pointing) remained significantly and independently related to motoric hyperactivity before and after covariance of nonexecutive abilities. Self-Ordered Pointing was not related to ADHD as a whole in our earlier study (Séguin et al., 1999). That finding was consistent with other work on the absence of a relation between verbal working memory and ADHD (Pennington et al., 1996). However, other studies found an absence of relation for verbal but not nonverbal working memory with ADHD (Murphy, Barkley, & Bush, 2001), whereas another found relations with both verbal and spatial working memory (McInnes, Humphries, Hogg-Johnson, & Tannock, 2003). Inconsistent in appearance, none of those other studies had controlled for nonexecutive abilities relevant to executive function, physical aggression, or CP, and ADHD diagnoses may not have been predominantly characterized by motoric hyperactivity. However, as can also be seen here, not all measures of working memory were independently related to motoric hyperactivity. Further, the deficit in working memory independently related to hyperactivity is not likely to be a function of low intelligence as others have proposed (Murphy et al., 2001).

Methodological Issues

The methodological features of this study may be summarized by (a) large sample size, (b) community as opposed to clinical sample, (c) documentation of childhood and adolescent history of problem behavior, (d) specificity to symptoms of physical aggression and motoric hyperactivity instead of the broader constructs of CD–CP delinquency and of HIA–ADHD, (e) a neuropsychological model that examined and controlled for nonexecutive abilities relevant to executive function (e.g., IQ and general memory) and a basic but central executive function process relevant to several stages of problem solving (i.e., working memory assessed with three measures), and (f) group assignment corrected for probabilities of belonging to a trajectory instead of an assumption of 100% precision in group assignment. These methodological differences may explain why the range of differences in working memory between our extreme trajectories before we dichotomized physical aggression was greater than the average 0.6 *SD* difference that Morgan and Lilienfeld (2000) reported in their meta-analysis of antisocial behavior and executive function. Had we focused exclusively on the four physical aggression trajectories, our standardized mean difference for uncorrected working memory scores were greatest for physical aggression (*SD* = 1.10, a large effect; Cohen, 1992), almost double the average range reported by Morgan and Lilienfeld and roughly double the range we found for the extreme groups using the four hyperactivity trajectories.

Our study also presents some limitations. Creating the high and low trajectory groupings was a useful compromise that allowed us to test for additive and interactive effects but that reduced the working memory standardized mean difference to about a standard deviation of 0.6 for physical aggression (a medium effect size). The fact that we still find an effect on working memory after taking into account nonexecutive abilities and hyperactivity is certainly an addition to that literature which typically does not control for nonexecutive factors and comorbidity. To be more comprehensive, we could have complemented our measures of physical aggression and hyperactivity with measures of impulsivity, inattention, opposition, and the nonviolent components of CD and delinquency. We also recommend that future studies of executive function in CP or HIA problems examine histories of physical aggression and motoric hyperactivity simultaneously because of their likely additive relation on neuropsychological outcome and because many tests that were significantly related to hyperactivity in our preliminary one-factor tests were accounted for by physical aggression in our two-factor model. Further, a broader range of working memory tasks is also likely to better reveal impairments related to physical aggression, motoric hyperactivity, or both.

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Table 1

Distribution of Weighted and Nonweighted Physical Aggression and Hyperactivity Trajectories Across the Total Sample and the Laboratory Sample

Trajectory		Total sample				Laboratory sample			
		Nonweighted		Weighted		Nonweighted		Weighted	
Physical aggression	**Hyperactivity**	***n***	**Cell %**	***n***	**Cell %**	***n***	**Cell %**	***n***	**Cell %**
Never	Never	107	10.32	77.26	7.45	66	21.78	44.96	14.84
	Low desisters	81	7.81	62.30	6.01	29	9.57	23.09	7.62
	Moderate desisters	3	0.29	6.87	0.66	1	0.33	1.58	0.52
	Chronic	0	0.00	0.29	0.03	0	0.00	0.15	0.05
Low desisters	Never	89	8.58	116.56	11.24	6	1.98	24.21	7.99
	Low desisters	304	29.32	296.75	28.62	50	16.50	58.78	19.40
	Moderate desisters	120	11.57	125.18	12.07	30	9.90	29.60	9.77
	Chronic	5	0.48	12.18	1.17	4	1.32	5.48	1.81
Moderate desisters	Never	2	0.19	9.80	0.95	0	0.00	2.39	0.79
	Low desisters	94	9.06	97.94	9.44	28	9.24	26.30	8.68
	Moderate desisters	173	16.68	149.58	14.42	65	21.45	53.84	17.77
	Chronic	29	2.80	36.85	3.55	12	3.96	16.03	5.29
Chronic	Never	1	0.10	0.71	0.07	1	0.33	0.39	0.13
	Low desisters	3	0.29	8.25	0.80	1	0.33	2.21	0.73
	Moderate desisters	22	2.12	27.70	2.67	9	2.97	11.00	3.63
	Chronic	4	0.39	8.77	0.85	1	0.33	3.00	0.99
Total		1,037	100.00	1,037	100.00	303	100.00	303.00	100.00

Table 2

Means and Standard Deviations for Cognitive Tests Raw Scores

Cognitive variables	***M***	***SD***	**Range (min–max)**	***N***
Vocabulary	44.11	11.61	11–75.5	298
Block design	10.50	2.79	1–15	295
Digit span	15.07	3.86	5–24	303
Paired associates learning	26.23	3.77	6–30	303
Number randomization	4.99	2.40	0–10	302
Self-Ordered pointing errors	9.01	5.25	0–28	302
Conditional Association trials with errors	49.89	37.53	3–153	299

Table 3

Correlations Among Cognitive Variables and Test Motivation

Variable	1	2	3	4	5	6	7	8
1. Vocabulary	—							
2. Block Design	.45[***]	—						
3. Digit Span	.29[***]	.34[***]	—					
4. Paired Associates	.42[***]	.29[***]	.36[***]	—				
5. Number Randomization	.25[***]	.33[***]	.39[***]	.24[***]	—			
6. Self-Ordered Pointing	.44[***]	.48[***]	.33[***]	.33[***]	.34[***]	—		
7. Conditional Association	.26[***]	.33[***]	.25[***]	.35[***]	.29[***]	.36[***]	—	
8. Test Motivation	.11	.16[**]	.08	.05	.06	.13[*]	.11[*]	—

Note. Correlations two-tailed Pearson.

[*] $p < .05$.

[**] $p < .01$.

[***] $p < .001$.

Table 4

Nonadjusted, Weighted, Standardized Marginal Means for Cognitive Tests and Motivation for Physical Aggression and Hyperactivity Categories

	Aggression				**Hyperactivity**			
	Low		**High**		**Low**		**High**	
Variable	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Vocabulary	0.34	0.51	−0.51	0.41	0.31	0.53	−0.43	0.41
Block Design	0.27	0.50	−0.42	0.45	0.18	0.53	−0.25	0.46
Paired Associates	0.17	0.55	−0.28	0.45	0.16	0.55	−0.24	0.44
Digit Span	0.11	0.57	−0.18	0.43	0.12	0.56	−0.18	0.45
Number Randomization	0.16	0.57	−0.27	0.42	0.10	0.55	−0.15	0.45
Self-Ordered Pointing	0.29	0.52	−0.46	0.43	0.25	0.53	−0.37	0.44
Conditional Association	0.20	0.54	−0.32	0.44	0.15	0.54	−0.23	0.45
Test Motivation	0.09	0.56	−0.15	0.44	0.14	0.54	−0.20	0.45
Weighted *N*	187.84		115.16		182.32		120.68	
Total *N*	303				303			

Table 5

Nonadjusted, Weighted, Standardized Cell Means for Cognitive Tests for Physical Aggression by Hyperactivity Categories

	Low physical aggression–low hyperactivity		Low physical aggression–high hyperactivity		High physical aggression–low hyperactivity		High physical aggression–high hyperactivity	
Variable	***M***	***SD***	***M***	***SD***	***M***	***SD***	***M***	***SD***
Vocabulary	0.44	0.65	−0.07	0.29	−0.30	0.32	−0.59	0.48
Block Design	0.28	0.64	0.21	0.31	−0.32	0.35	−0.45	0.53
Paired Associates	0.21	0.71	0.02	0.32	−0.12	0.35	−0.35	0.52
Digit Span	0.17	0.72	−0.12	0.37	−0.12	0.33	−0.20	0.51
Number Randomization	0.17	0.72	0.12	0.37	−0.27	0.30	−0.27	0.51
Self-Ordered Pointing	0.36	0.67	−0.01	0.28	−0.30	0.29	−0.52	0.53
Conditional Association	0.24	0.70	0.00	0.30	−0.30	0.30	−0.32	0.54
Test Motivation	0.13	0.71	−0.05	0.36	0.18	0.31	−0.27	0.53
Weighted *N*	151.02		36.82		31.29		83.87	
Total *N*	303							

Table 6

Effects of Behavior Trajectories, Physical Aggression by Hyperactivity Interaction, and Test Motivation on each Cognitive Variable (Model 1)

Cognitive test	**Effect**	***F***	***p***	**$R^2 - \eta^2$**
Vocabulary	Global	74.96	<.0001	0.21
	Physical aggression	97.99	< .0001	0.08
	Hyperactivity	37.35	< .0001	0.03
	P × H interaction	3.18	< .08	0.003
	Motivation	1.88	= .17	0.002
Block Design	Global	44.24	< .0001	0.13
	Physical aggression	88.91	< .0001	0.07
	Hyperactivity	0.70	= .40	0.001
	P × H interaction	0.01	= .90	< 0.001
	Motivation	25.20	< .0001	0.02
Paired Associates	Global	18.13	< .0001	0.06
	Physical aggression	24.46	< .0001	0.02
	Hyperactivity	8.24	< .005	0.007
	P × H interaction	0.02	= .88	< 0.001
	Motivation	2.10	= .15	0.002
Digit Span	Global	11.18	< .0001	0.04
	Physical aggression	6.23	< .013	0.005
	Hyperactivity	4.73	< .03	0.004
	P × H interaction	2.74	< .10	0.002
	Motivation	10.85	.0010	0.009
Number Randomization	Global	13.56	< .0001	0.05
	Physical aggression	35.36	< .0001	0.03
	Hyperactivity	0.09	= .76	< 0.001
	P × H interaction	0.22	= .64	< 0.001
	Motivation	0.39	= .54	< 0.001
Self-Ordered Pointing	Global	54.79	< .0001	0.16
	Physical aggression	77.88	< .0001	0.063
	Hyperactivity	17.03	< .0079	0.014
	P × H interaction	1.71	= .19	0.001
	Motivation	11.73	< .0076	0.010
Conditional Association	Global	23.89	< .0001	0.08
	Physical aggression	39.54	< .0001	0.03
	Hyperactivity	2.42	= .12	0.002
	P × H interaction	3.15	< .08	0.003
	Motivation	8.84	= .003	0.008

Note. Global *dfs* = (4, 1158) and (1, 1158) for all other effects. R^2 for global effects and partial η^2 for other effects. P × H = Physical Aggression by Hyperactivity.

Table 7

Multivariate Effects on Working Memory Tests (Model 2)

Effect	**Pillai’s trace**	***F***	***p***
Physical aggression	0.0253	9.96	< .0001
Hyperactivity	0.0075	2.94	= .0373
P × H interaction	0.0027	1.04	= .375
Vocabulary	0.0235	9.28	< .0001
Block Design	0.0939	39.81	< .0001
Paired Associates	0.0300	11.89	< .0001
Digit Span	0.0957	40.62	< .0001
Test Motivation	0.0049	1.90	= .1281

Note. All *df*s = 3, 1152. P × H = Physical Aggression by Hyperactivity.

Table 8

Effects of Combined Behavior Trajectories and Cognitive Variables on Working Memory Tests (Model 2)

	Number Randomization			**Self-Ordered Pointing**			**Conditional Association**		
Effect	***F***	***p***	$R^2 - \eta^2$	***F***	***p***	$R^2 - \eta^2$	***F***	***p***	$R^2 - \eta^2$
Global	34.01	< .0001	0.19	78.77	< .0001	0.35	33.32	< .0001	0.19
Physical aggression	11.56	0.0007	0.010	18.33	< .0001	0.016	11.23	.0008	0.01
Hyperactivity	0.59	0.44	0.001	7.56	0.0061	0.007	0.28	0.60	< 0.001
P × H interaction	0.00	0.98	< 0.001	0.76	0.39	0.001	2.91	0.09	0.003
Vocabulary	0.80	0.37	0.001	26.92	< .0001	0.023	0.67	0.41	0.001
Block Design	26.64	< .0001	0.023	100.74	< .0001	0.08	27.41	< .0001	0.023
Paired Associates	1.27	0.26	0.001	0.92	0.34	0.001	34.65	< .0001	0.029
Digit Span	92.13	< .0001	0.074	42.81	< .0001	0.036	11.16	0.0009	0.010
Test Motivation	1.62	0.20	0.001	1.58	0.21	0.001	2.57	0.11	0.002

Note. R^2 for global effects and partial η^2 for other effects; global *df*s = 7, 1162; *df*s for all other effects = 1, 1162. P × H: Physical Aggression by Hyperactivity.