Dissociation of the component processes of attention in healthy adults

John Gunstad a,*, Ronald A. Cohen b, Robert H. Paul b, Evian Gordon c,d,e

a Kent State University, Department of Psychology, Kent Hall, Kent, OH 44242, USA
b Brown Medical School, Department of Psychiatry and Human Behavior, RI, USA
c The Brain Resource International Database; Brain Resource Company, Paddington, UK
d Department of Psychological Medicine University of Sydney, Australia
e The Brain Dynamics Centre, Westmead Hospital, Westmead, Australia

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Abstract

Cohen’s [Cohen, R. (1993). The Neuropsychology of Attention. New York: Plenum Publishing] model of attention proposes four interrelated processes, namely Sensory Selective Attention, Response Selection/Control, Focus/Capacity, and Sustained Attention. Though this model has been supported in patient samples, it has not been examined in a healthy adult cohort. Using Principal Components Analysis, we examined the explanatory power of this model in 342 adults screened for significant medical and psychiatric history. The four derived components accounted for 58.7% of the total variance. Results were generally supportive of Cohen’s [Cohen, R. (1993). The Neuropsychology of Attention. New York: Plenum Publishing] model, though further clarification of the relationship between processing speed and more complex aspects of attention (e.g. working memory, set shifting) is needed. These findings support the notion that attention is not a unitary process, but instead comprised of distinct components. Future studies including both neuropsychological testing and functional neuroimaging may provide important insight into the underpinnings of attentional processes.

Keywords: Attention; Cognition

There is growing evidence that attention is the byproduct of multiple component processes rather than a unitary process (Heilman, Watson, & Valenstein, 1993; Cohen, 1993; Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991). Cohen (1993) proposed that attention that was comprised of four distinct but interrelated components. Sensory Selective Attention involves the discrimination of noise from targets and includes filtering, enhancement, and disengagement of information. These abilities can be assessed using tasks of basic auditory attention and orienting responses. Response Selection/Control is the active selection of responses as well as inhibition of inappropriate responses and has been measured using errors on Trail Making Test and Wisconsin Card Sort Test. Focus/Capacity refers to amount of information that can be processed at a given point in time and is limited by both structural and energetic factors. Tests that measure working memory and processing speed load on this component, including tasks such as reaction time and Digit Span Backward. Finally, Sustained Attention is the ability to maintain attention over time, which is strongly

* Corresponding author. Tel.: +1 330 672 2589; fax: +1 330 672 2589.
E-mail address: jgunstad@kent.edu (J. Gunstad).

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influenced by fatigability and vigilance. Decrement and variability of performance are key measures of Sustained Attention, including decrement in Continuous Performance Test vigilance and variability in response time on speeded tasks.

Since its proposal, Cohen’s (1993) model has been successfully applied to various patient populations, including adults with neurological brain disorders, medically ill children, persons with ADHD, and older adults with depression (Lockwood, Alexopoulos, & van Gorp, 2002; Lockwood, Bell, & Colegrove, 1999; Lockwood, Marcotte, & Stern, 2001). However, no study to date has examined this model in a large sample of healthy adults. While striking disorders of attention, such as hemi-neglect syndrome and ADHD, are well recognized, impairments of attention occur secondary to many medical and psychiatric conditions. Neurological conditions such as dementia, head injury, and seizure disorders have long been associated with reduced attention, and more recent work shows persons with cardiovascular disease, type 2 diabetes, and HIV also exhibit impaired attention (Cohen et al., 1999; Levinoff, Li, Murtha, & Chertkow, 2004; Hewer, Mussell, Rist, Kulzer, & Bergis, 2003; Mathias, Beall, & Bigler, 2004; Paul, Cohen, Navia, & Tashima, 2002). Similarly, psychiatric disorders such as schizophrenia, depression, and post-traumatic stress disorder are also linked to deficits in attention performance (Goller & Yehuda, 2002; Harvey et al., 2004; Moore, Palmer, & Jeste, 2004).

A better understanding of attention in healthy adults may provide important insight into normal and pathological attention. Therefore, we conducted a Principal Components Analysis on the Attention Test Performance of 342 adults without significant medical or psychiatric history. Based on Cohen’s (1993) model, we expected attention tasks to be categorized into four distinct but interrelated components.

1. Method

1.1. Overview

This study employed data from the Brain Resource International Database (Gordon, Cooper, Hermens, & Williams, 2005). Exclusion criteria for this database includes many medical conditions known to impact cognitive performance, including past or present history of traumatic brain injury, neurological disorder, and other medical conditions (e.g. hypertension, diabetes, cardiac disease, thyroid disease). The SPHERE-12 (Hickie, Davenport, Naismith, & Scott, 2001) was administered to exclude individuals with history of significant psychiatric disorders (e.g. attention deficit hyperactivity disorder, schizophrenia, bipolar disorder) and/or alcohol or drug use disorders. Subjects were excluded if they had a family history of attention deficit hyperactivity disorder, schizophrenia, bipolar disorder, or genetic disorder. Participants were also asked to refrain from caffeine and nicotine for at least 2 h and from alcohol for at least 12 h prior to testing. Finally, participants were also screened for sensory deficits that may impact testing.

1.2. Participants

A total of 354 adult participants were included in the present study. After deleting 12 cases with outlier data, a total of 342 were retained for analyses. Participants averaged 40.69 ± 15.70 years of age (range from 21 to 79) and 13.65 ± 3.94 years of education (range from 8 to 18). Approximately, 50.4% of the sample was male and 85.2% was of European descent.

1.3. Procedure

All participants voluntarily signed a written informed consent form to participate in the database. Prior to data acquisition, each subject was assigned an eight-digit identification number for anonymity, and subjects answered self-report web-based questions, including questions about medical information, psychosocial history, personality, and emotional experience. As described above, participants completed the CIDI to identify significant mental illness. Participants underwent neurocognitive testing lasting approximately 45 min.

Subjects were seated in a sound attenuated room, in front of a touch-screen computer (NEC MultiSync LCD 1530 V). Cognitive tests were administered in a fixed order using pre-recorded task instructions and the touch-screen computer was used for answers. Touch-screen technology, use of a number pad, and recording of verbalized responses were used
to gather test data. This computerized battery has been shown to have good validity and reliability (Paul et al., 2005; Williams et al., 2005).

1.4. Instrumentation

Measures were chosen to adequately represent Cohen's (1993) model and to match previously studies as closely as possible. Hypothesized loading of each measure appears in Table 1. Measures included:

**Digit Span Backward:** Subjects were presented with a series of digits presented individually for 500 ms and separated by a 1-s interval. The number of digits in each sequence was gradually increased from 3 to 9 and participants were asked to correctly reverse the number string using a keypad. The number of digits correctly reversed served as the dependent variable.

**Verbal Interference:** This test was a computerized modification of the Stroop Test (Golden, 1978). Participants are asked to verbally generate as many responses as possible in 30 s. Total number of correct items on the interference condition (e.g. color names presented in incongruent colors) served as the dependent variable.

**Switching of Attention:** This modified version of the Trail Making Test consisted of two parts. Switching of Attention—Number requires participants to connect numbers in ascending sequence (i.e. 1–2–3–, etc). The second test, Switching of Attention—Letter/Number, asks participants to connect numbers and letters in an ascending but alternating sequence (i.e. 1–A–2–B, etc.). The numbers 1–13 and the letters A–L were presented in circles on the touch-screen. Time to completion for each trial was employed.

**Motor Tapping Variability:** Subjects were required to tap a circle on the touch-screen with their index finger as quickly as possible for 60 s. To assess sustained performance, the average standard deviation of the pause between taps for right and left hands was used as the dependent variable.

**Choice Reaction Time Variability:** Participants attended to the computer screen as one of four circles was illuminated. Immediately following presentation, the subject then had to touch the illuminated circle as quickly as possible. Twenty trials were administered with a random delay between trials of 2 and 4 s. Variability in response time served as a dependent variable.

**Time Estimation Bias:** During this task, an object is illuminated on the computer screen for 1–12 s. Participants are asked to estimate how long the item was illuminated. The variability of average error bias served as a dependent variable.

**Oddball Response Time and Errors:** Participants were asked to quickly respond to 60 auditory targets in the presence of 280 background tones (17.6% targets). Items are presented at an average of 1 per second (range from .5 to 2.0 s) and pseudo-randomized to prevent consecutive targets from being presented. Average response time to target and number of errors were used as dependent variables.

**Letter Detection Response Time and Errors:** Similar to a 1-back task, participants were asked to respond whether the item currently being presented matched the previous item. Dependent variables from this task included average response time and total number of errors.

<table>
<thead>
<tr>
<th>Measure</th>
<th>Predicted component</th>
</tr>
</thead>
<tbody>
<tr>
<td>Digit Span Backward</td>
<td>Focus/Capacity</td>
</tr>
<tr>
<td>Verbal Interference</td>
<td>Focus/Capacity</td>
</tr>
<tr>
<td>Switching of Attention—Number</td>
<td>Response Selection/Control</td>
</tr>
<tr>
<td>Switching of Attention—Letter/Number</td>
<td>Response Selection/Control</td>
</tr>
<tr>
<td>Motor Tapping Variability</td>
<td>Sustained Attention</td>
</tr>
<tr>
<td>Choice Reaction Time Variability</td>
<td>Sustained Attention</td>
</tr>
<tr>
<td>Time Estimation Bias</td>
<td>Sensory Selective Attention</td>
</tr>
<tr>
<td>Oddball Response Time</td>
<td>Focus/Capacity</td>
</tr>
<tr>
<td>Oddball Errors</td>
<td>Sensory Selective Attention</td>
</tr>
<tr>
<td>Letter Detection Response Time</td>
<td>Focus/Capacity</td>
</tr>
<tr>
<td>Letter Detection Errors</td>
<td>Sensory Selective Attention</td>
</tr>
</tbody>
</table>
1.5. Data analysis

To promote interpretation of the model, measures were chosen after considering their theoretical importance to Cohen’s (1993) model of attention. More specifically, variables were categorized to ensure that all four domains of attention proposed by Cohen (1993) were represented in the analyses. Principal Components Analysis (PCA) with promax rotation was then conducted on the selected variables. Promax rotation was chosen as it allows components to be correlated (i.e. oblique rotation), one of the predictions of Cohen’s (1993) model. Confirmatory factor analysis (CFA) methods were not employed as exploratory analyses had not yet been conducted in this population and it was unknown whether the model would require modification prior to confirmatory testing. It was also unknown whether measures would load on multiple components (i.e. complex), information needed to appropriately test the model using CFA.

2. Results

PCA using promax rotation was conducted on the 11 variables. Kaiser–Meyer Olkin (KMO) measure of sampling adequacy was .704, above the cutoff for this measure of partial correlation among variables. Bartlett’s Test of sphericity yielded $\chi^2 = 616.12 \ (P < .001)$, suggesting there is adequate observed relationship to perform PCA.

Examination of eigenvalues, scree plot, and parallel analysis suggested four components. Variables were well defined by this solution and component loadings were generally high. Using a cutoff .32 for inclusion of a variable in interpretation, all variables were retained and none were complex. This four-component model accounted for 58.7% of the total variance. See Table 2. Specifically, the four components were identified as:

(1) Executive included Switching of Attention—Letter/Number, Verbal Interference, Switching of Attention—Number, and Digit Span Backward.
(2) Processing Speed was comprised of Letter Detection Response Time and Oddball Response Time.
(4) Sustained Attention was comprised of Motor Tapping Variability and Choice Reaction Time Variability.

Table 2
Component loadings and explained variance using PCA with promax rotation on Attention Test Performance

<table>
<thead>
<tr>
<th>Task</th>
<th>C1</th>
<th>C2</th>
<th>C3</th>
<th>C4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Switching of Attention—Letter–Number</td>
<td>.83</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Verbal Interference</td>
<td>−.78</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Switching of Attention—Number</td>
<td>.74</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Digits Backward</td>
<td>−.70</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Letter Detection Reaction Time</td>
<td></td>
<td>.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oddball Paradigm Reaction Time</td>
<td></td>
<td>.86</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Letter Detection Errors</td>
<td></td>
<td></td>
<td>.74</td>
<td></td>
</tr>
<tr>
<td>Time Estimation—variability in bias</td>
<td></td>
<td></td>
<td>.67</td>
<td></td>
</tr>
<tr>
<td>Oddball Paradigm Errors</td>
<td></td>
<td></td>
<td>.56</td>
<td></td>
</tr>
<tr>
<td>Motor Tapping—variability in time between taps</td>
<td></td>
<td></td>
<td></td>
<td>−.85</td>
</tr>
<tr>
<td>Choice Reaction Time—variability in reaction time</td>
<td></td>
<td></td>
<td></td>
<td>.48</td>
</tr>
</tbody>
</table>
% of explained variance            | 24.90| 13.35| 10.95| 9.49 |

Note. C1 interpreted as Executive. C2 interpreted as Processing Speed. C3 interpreted as Selection/Detection. C4 interpreted as Sustained Attention. All values under .32 are omitted.

Table 3
Correlation among PCA components using promax rotation

<table>
<thead>
<tr>
<th>Component</th>
<th>Exec</th>
<th>PS</th>
<th>S/D</th>
</tr>
</thead>
<tbody>
<tr>
<td>Executive</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing Speed</td>
<td>.13</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Selection/Detection</td>
<td>.22</td>
<td>.10</td>
<td></td>
</tr>
<tr>
<td>Sustained Attention</td>
<td>.10</td>
<td>.03</td>
<td>.01</td>
</tr>
</tbody>
</table>
Though oblique rotation was employed, correlations among the derived components were modest (see Table 3).

3. Discussion

The present study identified four distinct components in attentional abilities in healthy adults. Each component exhibited considerable coherence and tapped similar attentional phenomena. As a result, these findings provide further support for the notion that attention is not a unitary construct, but comprised of distinct components responsible for particular task demands.

Results from this sample of healthy adults are generally supportive of Cohen’s (1993) component model of attention, though some notable discrepancies emerged. Two of the four components derived in the present study are very similar to those originally hypothesized. The component we labeled Selection/Detection was comprised of errors from different tasks (e.g. Oddball, Time Estimation, Letter Detection) and target detection is an important element of Cohen’s (1993) Sensory Selective Attention. Similarly, our component of Sustained Attention involved performance consistency over time, a key feature of Cohen’s (1993) notion of Sustained Attention.

The two other components derived from the present study, Executive and Processing Speed, depart somewhat from Cohen’s (1993) model. Executive was comprised of measures that assess a wide variety of attention-related abilities, including working memory, psychomotor speed, response inhibition, and set shifting. This component includes measures hypothesized to load on either the Response Selection/Control or Focus/Capacity components of Cohen’s (1993) model. In contrast, the derived component Processing Speed was narrowly defined and comprised entirely of measures of response speed. Although the ability to respond quickly is an important element of Cohen’s (1993) notion of Focus/Capacity, its original description also includes other abilities, including working memory and psychomotor speed.

The exact reason for the departure from Cohen’s (1993) model of attention is unknown, as it may reflect the relative independence of information processing speed or properties of the employed cognitive tests. It is possible that response speed or information processing speed comprises a fundamental, independent aspect of attention that establishes the limits of performance for more complex attention abilities (e.g. working memory, digit span). Some evidence for this possibility already exists, as it is known that diminished processing speed helps account for the impaired attentional focus in conditions such as multiple sclerosis and HIV (Sweet, Rao, Primeau, Mayer, & Cohen, 2004; Paul et al., 2002). However, it is also possible that the current findings reflect the surface similarities of the employed measures rather than providing insight into attentional architecture. Many tasks from the computerized test battery are similar to those employed in clinical practice and likely engage multiple aspects of attention during completion. Further research may clarify these findings and provide important insight into the structure of attention. For example, the present study found that Digit Span Backward performance loaded with measures of executive control. This finding suggests that reversing a number string may require both basic attention and executive function abilities, raising the possibility that a more complex relationship exists among attention and other cognitive domains.

Another finding requiring further examination is the relatively weak correlations among the derived components of attention. Cohen’s (1993) model of attention suggests the four attentional components work in coordination to meet task demands. Although two components showed a modest relationship (Executive and Selection/Detection; \( r = .22 \)), the other correlations were much weaker (range from \( r = .01 \) to \( r = .13 \)). Such findings suggest that attentional components are much more independent than originally predicted by the model and raise the possibility that higher order cognitive abilities (e.g. executive function) are responsible for coordinating their efforts. Further work is needed to determine the interaction among attentional components as well as the degree to which they are governed by executive function abilities.

Despite these discrepancies, Cohen’s (1993) model better accounts the current findings than another widely cited model of attention, Mirsky et al.’s (1991) model of attention (e.g. Fried & Watkinson, 2001; Goldstein, Johnson, & Minshew, 2001; Strauss, Thompson, Adams, Redline, & Burant, 2000). Contrary to Mirsky et al. (1991), the present findings showed that multiple indices from the same instrument can load on different attentional components (e.g. Letter Detection and Oddball Paradigm Response Time load on one component and errors on another) and that attentional components are not fully independent of each other. These differences may help explain why a recent study was unable to support Mirsky et al.’s (1991) model using confirmatory factor analysis methods (Strauss et al., 2000).
Additional work is needed to clarify the underlying structure of attention, particularly studies involving neurological populations and functional neuroimaging. For example, one recent study found that Alzheimer’s disease differentially impacts the multiple aspects of attention and it is possible that other conditions have similar effects (Levinoff et al., 2004). Similarly, a recent functional magnetic resonance imaging (fMRI) study found greater connectivity between the right anterior cingulate cortex and right dorsolateral prefrontal cortex during set shifting tasks (Kondo, Osaka, & Osaka, 2004). Continued examination of various populations with multiple methods of neurocognitive assessment may clarify the mechanisms of complex attentional phenomena and identify the etiology of conditions such as ADHD and visual neglect.

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References


