PCBs and measures of attention and impulsivity on a continuous performance task of young Mohawk adults

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PCBS AND MEASURES OF ATTENTION AND IMPULSIVITY ON A CONTINUOUS PERFORMANCE TASK OF YOUNG MOHAWK ADULTS

by

Bita Behforooz

A Dissertation
Submitted to University at Albany, State University of New York
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School of Education
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PCBs and measures of attention and impulsivity on a continuous performance task of young Mohawk adults

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Abstract

Past animal and human studies have shown that exposure to PCBs can result in a wide range of negative toxic effects. However, only a few studies have investigated the relationship between PCB exposure and attention and impulsivity. The present study examined the relationship between current body burden levels of PCBs and attention and impulsivity in young adults ages 17 to 21 from the Mohawk Nation of Akwesasne. The community is concerned because PCBs from industrial effluent have contaminated the local ecology and entered the Mohawk’s food chain. Attention and impulsivity were measured by errors of omission and errors of commission respectively of the Conner’s Continuous Performance Test. The PCB measure was the sum of those PCB congeners detected in 50% of the participants. After adjusting for possible confounding variables, the results from the regression revealed no relationship between PCBs and attention and impulsivity. This work was supported by grants from the National Institute of Environmental Health Sciences (NIEHS-ESO4913-10; ES10904-06), and the National Center on Minority Health and Health Disparities (NCMHD- 1P20MD003373-01). The content is solely the responsibility of the author and does not necessarily represent the official views of the National Center on Minority Health and Health Disparities, or the National Institutes of Health.
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Chapter 1

Introduction

Polychlorinated Biphenyls (PCBs) are a family of man-made chemicals made from the chlorination of a biphenyl molecule (Erickson, 1986; Zabik, 1983). They were produced in vast qualities world-wide between the 1930s and the 1970s and were mainly used in capacitors and transformers in industries (Erickson, 1986, 2001). Nonetheless, their properties have turned the chemical into a major source of environmental contamination (Holoubek, 2001), which has raised concerns about potential human health effects.

Concerns about PCB Exposure

Initial concerns over the environmental and human health impact of PCBs arose a few decades after the introduction of PCBs into the market. Researchers in several countries found that the chemical was accumulating and contaminating the environment (Jensen, 1966; Jensen, Johnels, Olsson, & Otterlind, 1969). Concerns over the toxicity of PCBs increased after two major human poisoning episodes. The first poisoning episode in 1968 took place in Japan where people ingested contaminated rice oil used in cooking. In 1978, a second poisoning occurred in Taiwan that was very similar to the one that had occurred in Japan in which a leaking heat exchanger contaminated cooking rice oil (Webber, 1988). These two poisoning incidents, also known as the Yusho and the Yu-Cheng incidents (Webber) involved massive PCB exposure; nonetheless, the increasing concerns over PCBs’ toxicity and bioaccumulation in the mid-1970s led to The Toxic Substances Control Act of 1976 in the United States which was further revised in 1979 (Erickson, 2001; Ross, 2004).

Even though the bans led to a decline in PCB residues (Ross, 2004), their resistance to degradation makes PCBs a major source of concern. PCBs bioaccumulate in fat and
biomagnify within the food chain and, as a result, accumulation increases as one moves higher in the food chain (Erickson, 1986, 2001; Johnson, Hicks, & De Rosa, 1999; Ross). Since humans are on top of the food chain, bioaccumulation in humans is very high (Chen, Wang, Yu, Liao, & Lee, 2006; Johnson et al.).

PCBs have entered the environment through industrial waste and most hazardous waste sites are located near these industries (Holoubek, 2001). The primary route of PCB exposure for the general public is through the food chain (Erickson, 2001).

Mothers can transfer PCBs to their infants from their adipose tissue both prenatally through the placenta and postnatally through breastfeeding (Winneke et al., 2005). Although the transfer of PCBs via breastfeeding is two to three times higher than fetal exposure in the utero (Winneke et al.), many studies show that prenatal PCB exposure is associated with more negative outcomes than lactation (Darvill, Lonky, Reihman, Stewart, & Pagano, 2000; Fein, Jacobson, Jacobson, Schwartz, & Dowler, 1984; Jacobson & Jacobson, 1996, 2003; Jacobson, Jacobson, Padgett, Brumitt, & Billings, 1992; Lai, Guo, Yu, Ko, & Hsu, 1994; Lai et al., 2002; Stewart et al., 2003a). Nevertheless, some researchers have shown postnatal relationships (Jacobson, Jacobson, & Humphrey, 1990a).

*Research about PCB Effects*

Over the years, a great deal of research has been conducted to determine the toxicity and potential adverse health effects of PCBs. It is reasonable to investigate such effects, as PCBs have been found to impact certain aspects of brain and endocrine functioning and influence human growth and development (Danse et al., 1997; Guo, Chen, Yu, & Hsu, 1994; Schell, 1999; Schell et al., 2004; Seegal, Bush, & Brosch, 1994; Seegal et al., 2010).
**Endocrine System.** PCBs have been shown to affect multiple endocrine systems. The thyroid is an endocrine that is affected by PCBs, though findings are somewhat inconsistent. In both animal and human studies, PCB exposure has been linked to a reduction of thyroid hormones (Brouwer et al., 1998; Goldey, Kehn, Lau, Rehnberg, & Crofton, 1995a; Morse et al., 1993; Schell et al., 2004). Normal brain development requires certain levels of thyroid hormone during critical periods of prenatal development (Porterfield, 1994; Porterfield & Hendrich, 1993). Hypothyroidism during gestation can have a detrimental effect on brain development. In fact, hypothyroidism has resulted in persistent hyperactivity in rats (Goldey, Kehn, Rehnberg, & Crofton, 1995b) and thyroid hormone deficit during pregnancy in humans has been linked to adverse neuropsychological effects (Haddow et al., 1999) and lower motor competence (Pharoah, Connolly, Hetzel, & Ekins, 1981).

Dopamine is also affected by PCBs. A decrease in the brain’s dopamine level has been observed in both animals and humans who are exposed to PCBs (Seegal et al., 1994, 2010) which in turn can result in cognitive and behavioral disturbances (Jones & Miller, 2008). The negative relationship between PCBs and thyroid hormones and dopamine levels in animal and human studies should raise concern about the possible effects of PCB exposure on such domains as activity level and the ability to sustain attention.

**High levels of PCB exposure.** Occupational studies have been conducted to investigate the effects of high chronic exposure to PCBs. Although general conclusions are not always consistent among the different PCB studies there are some similarities in findings and some consistency with the animal studies (Persky, 2001). High occupational exposure to polychlorinated biphenyls has been associated with a variety of physiological and toxic effects such as skin abnormalities (chloracne, folliculitis, juvenile acne, and oil-dermatitis)
and liver abnormalities (Maroni, Colombi, Arbosti, Cantoni, & Foa, 1981). Victims of the two major human poisoning episodes in Japan and in Taiwan also suffered from symptoms such as chloracne, hyperpigmentation of the skin, eye discharge, fatigue, nausea, and liver disorders (Danse et al., 1997; Kuratsune, Yoshimura, Matsuzaka, & Yamaguchi, 1972).

**Low levels of PCB exposure.** Epidemiologic studies have been conducted to look at the health effects of PCB exposure at background levels that do not cause acute toxic effects. To date there are six major human cohort studies (Michigan, Oswego, North Carolina, Netherlands, Germany, and Faroe Islands) that have investigated the psychological and behavioral effects of PCBs on infants and children. The results of these epidemiologic studies suggest that there are some negative cognitive and behavioral effects associated with low levels of PCBs. These results will be reviewed below.

**Sensory and motor.** The Brazelton Neonatal Behavioral Assessment Scale (NBAS) has been used in a number of studies (Jacobson, Jacobson, Fein, Schwartz, & Dowler, 1984b; Lonky, Reihman, Darvill, Mather, & Daly, 1996; Rogan et al., 1986; Stewart, Reihman, Lonky, Darvill, & Pagano, 2000) in order to investigate the relationship between PCB exposure and sensory and motor behavior in infants. Negative effects were found in Michigan (Jacobson et al.), Oswego (Lonky et al.; Stewart et al.), and North Carolina (Rogan et al.). However, most studies using older children have shown no relationship between PCB and motor function (Després et al., 2005; Grandjean et al., 2001; Jacobson, Jacobson, & Humphrey, 1990b).

**Cognitive and memory.** Many of the human cohort studies have looked at the effects of PCBs on memory and cognitive functioning (Darvill et al., 2000; Jacobson & Jacobson, 1996; Nakajima et al., 2006; Newman et al., 2006; Patandin et al., 1999; Stewart, Reihman,
Lonky, Darvill, & Pagano, 2003b; Winneke et al., 1998). However, the findings among the different studies regarding cognitive outcomes are somewhat inconsistent.

Memory and cognitive functioning in these studies have been assessed by a number of different measures with various age groups and exposure situations. Winneke et al., (1998) used the Bayley Scales of Infant Development (BSID) with 7 month old children. BSID’s mental development index (MDI) was used to assess children’s cognitive development. Negative relationships were found between the sum of PCBs in maternal milk and children's MDI. This scale was also used in other studies looking at the effects of prenatal PCB exposure and mental development in 6 month old Japanese infants with no significant findings (Nakajima et al., 2006).

The Fagan Test of Infant Intelligence (FTII) has also been widely used in the different cohorts. Using this scale, Darvill et al. (2000) found a significant negative relationship between prenatal PCB exposure and FTII for 6 and 12 month old infants in Oswego. Other measures used have been the Wechsler Intelligence Scales for Children (Jacobson & Jacobson, 1996), the Kaufman Assessment Battery for Children (K-ABC) (Patandin et al., 1999), the McCarthy Scales of Children’s Abilities (Stewart et al., 2003b), the Ravens Progressive Matrices (RPM) (Newman et al., 2006), the Woodcock Johnson Tests of Cognitive Ability (WJ-R) (Newman et al.), and the Test of Memory and Learning (TOMAL) (Newman et al.). Findings from a meta-analysis conducted by Ribas-Fito, Sala and Sunyer (2001) on the effects of PCBs on cognition showed a relationship between the two in most studies that had investigated 4 year olds. In general, studies showed an association between in utero PCB exposure and cognitive and memory impairments during infancy and childhood.
Behavioral effects. Despite the large body of research looking at the cognitive effects of PCB exposure, few studies have looked at the relationship between PCBs and behavioral measures in humans. Animal studies of prenatal and postnatal exposures to PCBs show a relationship between PCBs and motor activity and hyperactivity (Agrawal, Tilson, & Bondy, 1981; Berger et al., 2001; Bowman, Heironimus, & Allen, 1978; Carpenter, Hussain, Berger, Lombardo, & Park, 2002; Chou, Miike, Payne, & Davis, 1979; Daly, Stewart, Lunkenheimer, & Sargent, 1998; Holene, Nafstad, Skaare, & Sagvolden, 1998; Rice, 1997b; Tilson, Davis, McLachlan, & Lucier, 1979; Ulfstrand, Sodergren, & Rabol, 1971).

Rice (2000) has also noted some similarities between behavioral impairment in monkeys exposed to PCBs and some of the characteristics of attention deficit hyperactivity disorder (ADHD) found in children, such as the inability to learn from the consequences of past actions. Adult rats exposed to PCBs exhibited behaviors similar to hyperactive rats and boys (Berger et al., 2001).

In the early studies of the children accidentally exposed to massive doses of PCBs (Chen, Yu, Rogan, Gladen, & Hsu, 1994; Harada, 1976), effects on children's activity levels were noted, however the nature of the effects varied. The offspring of Japanese women who had ingested contaminated rice oils were hypotonic (Harada) while the Taiwanese exposed children were more active and had more behavioral problems than an unexposed control group (Chen et al.).

In general both human and animal studies show that in utero exposure to PCBs is associated with more developmental neurotoxicity than postnatal exposure. In their cross-species comparison study of the different effects of PCB exposure on various rodents and primates including humans, Tilson, Jacobson, and Rogan (1990) found that PCB exposure
altered activity level, learning, motor functioning, mental development, hyperactivity, and caused behavioral problems. However, the symptoms were not always consistent among the different species. In fact opposing results were found at times even in the same species.

*Sustained Attention*

Sustained attention or vigilance is the ability to maintain attention “for infrequent but critical events over sustained periods of time” (Corkum & Siegel, 1993, p. 1218). Sustained attention and impulsivity are related to a number of disorders such as the attention deficit hyperactivity disorder (ADHD) or learning disabilities (American Psychiatric Association, 2000). Many studies have been conducted to investigate the relationship between ADHD and its impact on school functioning. In general, ADHD students tend to perform more poorly academically than their peers. According to Barkley et al. (1990), ADHD students are suspended and expelled more from schools and also a larger number of them drop out of school. Adults with ADHD also have lower academic achievements with larger numbers dropping out of college (Murphy & Barkley, 1996).

Sustained attention and impulsivity are often measured by the CPT, which is a computerized measure of various aspects of attention and vigilance (Conners, 2000). It was originally developed by Rosvold, Mirsky, Sarason, Bransome, and Beck as a tool to assess brain damage (Rosvold, Mirsky, Sarason, Bransome, & Beck, 1956). The use of a computerized measure of behavior instead of a questionnaire allows the researcher to assess the subject’s actual behavior thus generating more objective behavioral data (Riccio, Reynolds, & Lowe, 2001). The test measures a person’s ability to identify and respond to specific infrequent stimuli at random intervals while inhibiting responses to non-target stimuli (Conners).
The X-type CPT is a version of CPT that requires the subject to press a key every time a letter appears on a computer screen that is not the letter X (the target letter). Errors of omission (the number of targets missed) reflect inattention and errors of commission (the number of incorrect responses to nontargets) indicate impulsivity (Conners, 2000). These measures allow assessment of the ability to sustain attention during a simple test of vigilance.

In recent years the CPT has been used to assess children and adults with ADHD (Barkley, 1990) and evaluate medication effects and nicotine effects for schizophrenic populations (Earle-Boyer, Serper, Davidson, & Harvey, 1991; Levin, Wilson, Rose, & McEvoy, 1996). The CPT has also been used in other studies investigating effects of attention and impulsivity of prenatal substance exposure (Leech, Richardson, Goldschmidt, & Day, 1999; Noland et al., 2005; Streissguth et al., 1986; Streissguth, Martin, Barr, Sandman, & Darby, 1984). For example, prenatal exposure to marijuana was related to inattentiveness as measured by omission scores (Noland et al.). The CPT has also been used to look at neurobehavioral effects of occupational exposure to neurotoxic chemicals (Estrin et al., 1987; Tsai & Chen, 1996). In these studies, CPT performance was adversely affected by chemical exposure.

A few human studies have investigated the relationship between PCB exposure and attention and impulsivity using different forms of CPT (Grandjean et al., 2001; Jacobson & Jacobson, 2003; Jacobson et al., 1992; Stewart et al., 2003a, 2005; Vreugdenhil, Mulder, Emmen, & Weisglas-Kuperus, 2004a). Stewart et al. (2003a) found that 4.5 year olds who were more highly exposed to PCBs prenatally had significant increases in their commission errors. Similar results were found for the same group of children at 8 and 9.5 years of age (Stewart et al., 2005). Jacobson and Jacobson’s study also investigated the relationship
between PCB exposure and attention and impulsivity using the CPT in children when they were aged 4 years and again at age 11 years. They also found more errors of commission at age 11. Prenatal PCB exposure was related to reaction time in Netherlands using a modified version of a Simple Reaction Time Test (Vreugdenhil et al.). Similarly, in Faroe Islands, umbilical cord PCB level was related to attention as measured by reaction time at age 7 (Grandjean et al.) while other studies examining the influence of PCB exposure on children's sustained attention found no relationship at the age of 4 (Jacobson et al.). The limited amount of human research on this topic, despite the fact that animal studies suggest a relationship, and the inconsistent findings, indicate a need for more studies in this area.

The Present Study

The present study adds to the research concerning the relationship between PCBs and impulsivity and attention in a group of young adults using the Conners’ Continuous Performance Task (CPT). The study was conducted at the Mohawk Nation of Akwesasne which is located along the St. Lawrence River between upstate New York, Ontario, and Quebec. A National Priority Superfund site and two New York State Superfund sites are upstream of Akwesasne (DeCaprio et al., 2005). PCBs from industrial effluent have contaminated the local ecology and entered the Mohawks’ food chain. The community is concerned about the impact of industrial pollution on its environment and members, especially the young people. A sample of young adults from the community participated in the Young Adult Well-being Study (YAWBS) which investigated various physical, health, and cognitive outcomes of PCB exposure of Akwesasne youth whose mothers were likely to have been exposed to PCBs by eating local contaminated food before their pregnancy. As adults they were likely to have been exposed to PCBs through local food consumption. The
young adults had previously participated in the Mohawk Adolescent Well-Being Study (MAWBS) (Newman et al., 2006, 2009; Schell et al., 2004, 2008). In the MAWBS studies, PCB level was related to measures of long term memory (Newman et al., 2006) but not to behavioral rating measures of attention (Aucompaugh, 2005).

The present study investigates the relationship between current blood PCB levels in a group of young adults, and attention and impulsivity as measured by the Continuous Performance Test’s omission and commission scores.
Chapter 2

Literature Review

Polychlorinated Biphenyls (PCBs)

History of PCB production. Polychlorinated biphenyls (PCBs) are a group of persistent organic pollutants (POPs) made from the iron catalyzed chlorination of a biphenyl molecule (Holoubek, 2001; Zabik, 1983). PCBs do not occur naturally in the environment (Erickson, 1986). In the United States, PCBs were initially produced in 1923 (National Research Council, 1979) and were first manufactured commercially in 1929 (Erickson; Swain, 1983) by the Anniston Ordinance Company in Alabama which was renamed in 1930 as the Swann Chemical Company and renamed again as the Monsanto Industrial Chemical Company in 1935 (Imslip, 2004).

The Monsanto Corporation in the United States was the major manufacturer of PCBs in the world. Aroclor, produced by the Monsanto Chemicals Company, is the most familiar trade name for PCBs in the United States (Connell, 2005; Erickson, 1986). Approximately 1.3 billion pounds of PCBs were produced worldwide by 1976 and of this amount about 1.25 billion pounds were produced in the United States by the Monsanto Corporation (Erickson).

Chemical structure of PCBs. Polychlorinated biphenyls consist of 209 congeners (PCBs with different numbers of chlorine atoms) formed by the attachment of 1 to 10 chlorine atoms to a biphenyl, two 6-carbon benzene rings linked together by a single carbon to carbon bond. Of the 209 possible congeners of PCBs only about 130 have been produced for commercial use (Connell, 2005). Figure 1 shows the structural formula for PCBs (PCBs
and Chemistry, n.d.). The chlorine atoms can be at the ortho, meta, and/or para position on each or both benzene rings (Norstrom, 1988).

*Figure 1. Structural formula for PCB*

```
2, 2' and 6, 6' - ortho position
3, 3' and 5, 5' - meta position
4, 4' - para position
```

*Chlorine content of PCBs.* The chlorine content of PCBs varies from 19-71% and depends on the extent of chlorination during its production (Erickson, 1986). In order to indicate the amount of chlorine in its products, the Monsanto Chemical Company gave its products a four digit number (i.e.: 1221, 1232, 1242, 1248, 1254, and 1260). The first two digits (12) represented the 12-carbon atoms in the biphenyl nucleus which indicated that the molecule was a PCB, and the last two numbers showed the percentage of chlorine for each PCB congener by weight (Connell, 2005; Myers, 2007; Safe, 1994). In general, the toxicity of a PCB molecule depends on its degree of chlorination (the more chlorinated the more
toxic) and the position of the chlorine atom(s) in the molecule which affects the planarity of the molecule.

*Planarity of PCBs.* Ortho-substituted PCBs have one or more chlorine atoms in one or more of the ortho 2, 2', 6, 6' positions. Because chlorine atoms are larger than hydrogen atoms, a complete rotation about the carbon-carbon bond is not possible in the ortho PCB congeners. Non-ortho or coplanar PCBs are PCB molecules that do not have any chlorine atoms on any of the four ortho positions in the molecule. In non-ortho coplanar PCBs the phenyl rings are flat and can rotate about the carbon-carbon bond making the molecule unstable. The most toxic PCBs are the non-ortho congeners which are those molecules with chlorine atoms on some or all of the meta and para positions (3, 3', 4, 4', 5, 5') because it allows the PCB to interact with other receptors (Connell, 2005).

*Industrial uses of PCBs.* The physical and chemical properties of PCBs vary by congener and by the degree of the molecule’s chlorination (Safe, 1994). The unique physical and chemical properties of PCBs that are responsible for many of its industrial uses are its chemical stability, low flammability, low aqueous solubility, and electrical insulating properties (Connell, 2005; Erickson, 2001; Safe). Also, the more chlorinated PCBs have lower aqueous solubility, flammability, and reactivity (Connell).

Given their stability and heat resistance, PCBs were extensively used in capacitors and transformers (Erickson, 1986, 2001). For example, because of their high thermal stability, PCBs were used in capacitors and transformers as a heat transfer fluid to transfer heat to the outer shell of the equipment; they thus served as coolants. Also, because they are poor electrical conductors and nonflammable they have been used in factories to reduce the risk of fires (Connell, 2005).
In the United States, PCBs have been used in completely closed systems, nominally closed systems, and open-ended applications (Erickson, 2001). PCBs involved in completely closed systems include large capacitors and transformers that have high amounts of PCBs (Erickson). However, the PCBs are not in direct contact with the environment unless there is a leakage (Connell, 2005). The following description is based closely on Connell. Nominally closed systems include smaller capacitors. They are used as heat transfer systems, hydraulics, and lubricants (Erickson). They contain small amounts of PCBs. Therefore, it is difficult to recover and destroy the small amounts of PCBs found in such units. In 1971, 90% of PCB use in America was for completely closed systems or nominally closed systems.

PCBs in open-ended applications are in direct contact with the environment and result in direct environmental contamination. Open ended use included fireproofing agents in products such as paints, inks, adhesives, copying paper, and plastics (Connell, 2005). Because PCBs reduced the risk of fires, some city codes required capacitors and transformers in schools, offices and hospitals to use PCBs. In addition, some insurance companies also required the use of PCBs (Ross, 2004).

*Environmental distribution, transport and contamination of PCBs.* PCBs have mainly contaminated the environment through industries and most sites of concern are located near these industries (Holoubek, 2001). Initial concerns about PCBs were not great, thus their use and disposal was not monitored. Concerns over the presence of PCBs in the environment began in the late 1960s, when researchers in Sweden found PCBs in eagles, herrings, and different marine animals (Jensen, 1966; Jensen et al., 1969). In the United States, the presence of PCBs in the environment was noted in 1968 (Ross, 2004). Further studies around this time period showed the presence of PCBs in wildlife (Holden & Marsden, 1967; Holmes,
Simmons, & Tatton, 1967; Jensen et al.), food (Fries, 1972; Kolbye, 1972), and humans (Biros, Walker, & Medbery, 1970; Price & Welch, 1972).

In most cases, PCBs have been disposed in water ways resulting in the contamination of the soil and sediments of the water ways (Holoubek, 2001). PCBs bond to the organic parts of soils and sediments and their mobility depends on the soil’s characteristic such as bulk, density, and moisture content. Also, the larger congeners tend to be less mobile (Connell, 2005). Waters with low particulates have low levels of PCBs in the water but high concentration of PCBs can be found in the bottom in the sediment (Swain, 1983) because PCBs settle on the bottom of water instead of floating on top, and are transported by the movement of the sediment (Connell).

**Bioaccumulation and biomagnification.** Since PCBs have a high degree of chemical and biological stability and are lipophilic, they bioaccumulate in the fatty tissues of the organisms low in the food chain and biomagnify when consumed by organisms higher in the food chain (Erickson, 1986, 2001; Johnson et al., 1999; Ross, 2004). As a result PCBs have been found in different species such as fish, marine animals, birds, plants, mammals, and humans (Bacci & Gaggi, 1985; Biros et al., 1970; Bremle, Okla, & Larsson, 1995; Chu, Cai, & Xu, 1999; Fries, 1972; Holden & Marsden, 1967; Holmes et al., 1967; Jensen, 1966; Jensen et al., 1969; Price & Welch, 1972). Since humans are on top of the food chain, bioaccumulation in humans is great (Chen et al., 2006; Johnson et al.). Although the congeners differ in this regard, PCBs are persistent in the environment and are resistant to transformation and degradation.

**Routes of exposure.** Routes of exposure are both industrial and non-industrial. Humans are exposed to PCBs during the production of PCBs, by accidental leakage in
factories, during the production and use of goods containing PCBs such as paints, by residing in a contaminated environment, by consuming contaminated food, via breast milk, or in utero (Dekoning & Karmaus, 2000; Erickson, 2001; Reggiani & Bruppacher, 1985; Winneke et al., 2005). Exposure can occur in both a chronic or acute way (Reggiani & Bruppacher). PCBs can affect humans through inhalation, dermal absorption and ingestion (Carpenter, 2006). However, the general public’s exposure to PCBs is mainly through ingesting contaminated food (Erickson).

PCB concentration in organisms depends on the lipid content of the organ. The higher the lipid content, the higher the PCB level (Dekoning & Karmaus, 2000). PCBs are found in adipose tissue, cord blood, placenta, blood lipids, and breast milk (Schecteta, Kassisb, & Päpkec, 1998) and they move by the lipid component of the blood to the various tissues in the human body. Therefore, the distribution of PCBs in the body is determined by the lipid content of the tissue (Dekoning & Karmaus).

Mothers can also transfer PCBs to their infants from their adipose tissue both prenatally through the placenta and postnatally through breastfeeding (Winneke et al., 2005). Animal studies show placental transfer of PCBs into the developing fetus of pregnant rabbits after they were fed Aroclor 1221 and 1254 during gestation. Furthermore, the concentration of PCBs in the maternal liver of these rabbits was less than in the fetal liver (Grant, Villeneuve, McCully, & Phillips, 1971). Studies show a higher concentration of PCBs in breast milk than in maternal and cord serum (Jacobson, Fein, Jacobson, Schwartz, & Dowler, 1984a). Also, the transfer of PCBs via breastfeeding is two to three times higher than fetal exposure in utero (Winneke et al.) because of the higher fat content found in breast milk than maternal and cord serum (Jacobson, Jacobson, Schwartz, Fein, & Dowler, 1984c). According
to Jacobson et al. (1984c), there are lower levels of PCBs in the cord serum than maternal serum because of the placenta’s role as a “partial barrier” (p. 379).

**PCB bans.** In 1971, as a result of concerns over PCBs’ toxicity and bioaccumulation, the Monsanto Chemical Company voluntarily restricted the production of PCBs to less chlorinated PCBs (PCBs with less than 60% chlorination) and restricted sales to closed systems. Also when a different fluid became available for use the company voluntarily ceased production (Ross, 2004) first at Anniston, Alabama, where production stopped in 1970 and later at the Sauget, Illinois where production ended in 1977 (NRC, 1973).

In the United States, governmental regulations were also made in the 1970s. The Toxic Substances Control Act (TSCA) of 1976 in the United States allowed the EPA to regulate PCB production, use, and disposal. In 1978 initial bans were put in place, and finally in 1979 PCB production was banned with strict regulations on its use (Erickson, 2001; Ross, 2004). Similar bans have been made in other industrialized nations and as a result PCB levels in humans have decreased in the United States (Erickson). In 1995, median PCB levels in the United States were between 2 to 7 ppb in whole serum, and the average PCB levels in the adipose tissue and milk in industrialized nations were around 1 ppm (Kimbrough, 1995).

**Effects of PCB Exposure**

**Endocrine system.** The endocrine system includes a set of glands that secrete hormones which regulate various functions in the human body such as growth, development, metabolism, mood, behavior, etc. (Greenstein & Wood, 2006). PCBs have multiple endocrine effects particularly on thyroid and dopamine. Thyroid hormone is needed for normal brain development during critical periods of prenatal development (Porterfield, 1994; Porterfield & Hendrich, 1993). In fact, some researchers suggest that effects of PCBs on
brain development may be partially due to their ability to interfere with the amount of thyroid available to the fetus during gestation and during the first two years after birth (Porterfield; Zoeller, 2001). Dopamine on the other hand, is a neurotransmitter responsible for a number of central nervous system processes such as mood, motor activity, learning, cognition, and attention (Jones & Miller, 2008).

In animal studies, hypothyroidism has resulted in persistent hyperactivity in rats (Goldey et al., 1995b). Similarly in human studies, thyroid hormone deficit during pregnancy has been linked to adverse neuropsychological effects in the offspring (Haddow et al., 1999). Furthermore, lower maternal T₄ (thyroxine) has been related to lower childhood motor competence as measured by two manual dexterity tests that measured speed and accuracy in children (Pharoah et al., 1981). Low dopamine levels have also been associated with ADHD (Sullivan & Brake, 2003; Van der Kooij & Glennon, 2007).

Animal studies (Goldey et al., 1995a; Morse et al., 1993) and human studies (Koopman-Esseboom et al., 1994; Osius, Karmaus, Kruse, & Witten, 1999; Schell et al., 2004; Steuerwald et al., 2000) have been conducted to investigate the relationship between PCB levels and thyroid functioning. In general, there is some evidence that PCBs reduce circulating levels of thyroid hormones in both animals (Goldey et al.; Morse et al.) and humans (Koopman-Esseboom et al.; Osius et al.; Schell et al.) though findings are not consistent.

In general thyroid levels, particularly T₄, are sensitive to PCB exposure. A review by Brouwer et al. (1998) confirms this general finding. In experimental studies using animals, PCBs decreased T₄ with little to no effect on T₃ (triiodothyronine) while, in animals exposed to PCBs in the wild, FT₄ (free thyroxine) and T₃ were reduced.
Hypothyroidism has also been found in a Dutch study of human infants where PCB exposure was related to lower FT$_4$ and T$_4$ and higher TSH (thyroid stimulating hormone or thyrotropin) in infants and lowered plasma levels of maternal T$_3$ and T$_4$ (Koopman-Esseboom et al., 1994). Similarly in Germany, a positive relationship was found between PCB 118 and TSH, a negative relationship was found between PCBs 138, 180, 183, and 187 and FT$_3$ (free triiodothyronine), and no significant association was found with FT$_4$ in 7 to 10 year olds (Osius et al., 1999). The Faroe Islands study on the other hand found no significant relationship between PCB levels and thyroid functioning in human infants (Steuerwald et al., 2000). As part of the MAWBS project, Schell et al. (2004) examined the relationship in the adolescents between PCB body burden levels in the blood with TSH, T$_3$, T$_4$, and FT$_4$. In their analyses, PCB levels were negatively related to T$_4$, FT$_4$, and positively to TSH but were not related T$_3$ in 10 to 16 year olds. It must be noted that thyroid hormone levels of the participants while in this study were within the normal range.

Prenatal exposure of rats to PCBs has resulted in changes in the dopamine levels in the prefrontal cortex (Seegal, Brosch, & Okoniewski, 2005) which can result in changes in behavior. In fact, animal studies have found relationships between PCB exposure and behaviors regulated by the prefrontal cortex such as an increase in hyperlocomotor activity and hyperactivity (Bowman et al., 1978; Carpenter et al., 2002).

In animal studies, adult male monkeys exposed to Aroclor 1016 and Aroclor 1260 showed a significant decrease in dopamine levels in the brain compared to the control group (Seegal et al., 1994). Furthermore, decreasing dopamine levels in neonatal rat pups has resulted in temporary hyperactivity (Shaywitz, Yager, & Klopper, 1976) and memory and learning deficits (Archer et al., 1988). Moreover, rats whose dopamine levels were reduced in
this manner in infancy continued to have behavioral impairments as adults (Castaneda, Whishaw, Lermer, & Robinson, 1990). Dopamine reduction has also been observed in humans exposed to PCBs at work (Seegal et al., 2010). In conclusion, PCBs seem to affect thyroid and dopamine levels in both animals and humans and thus may have an affect on such domains as attention and behavior.

High levels of human exposure: Yusho and Yu-Cheng. To date there have been two major human PCB poisoning episodes where the source of contamination was food. The first major PCB poisoning incident is known as the Yusho (rice oil) incident. It occurred in 1968 in the western part of Japan where approximately 1,800 people were affected. Upon investigation, researchers at Kyushu University linked the epidemic to the Kanemi brand rice oil, which had been contaminated with large amounts of Kanechlor 400 PCBs which is a brand of PCB with a chlorine content of 48% (Okumura, 1984; Webber, 1988). Some of the rice oil produced contained about 2000 to 3000 ppm of Kanechlor 400 (Kuratsune et al., 1972). Subsequent analysis revealed elevated levels of polychlorinated dibenzofurans (PCDFs) and polychlorinated quarterphenyls (PCQs) in addition to PCBs (Okumura; Webber).

The second poisoning episode took place in central Taiwan in 1978-1979 and is known as the Yu-Cheng incident. Again it was found that cooking rice oil (the C-rice oil) had been contaminated during production. The rice oil was contaminated by Kanechlor 400 (48% Cl) and Kanechlor 500 (54% Cl) at high concentrations of 65 and 108 ppm, respectively (Hsu et al., 1984, 1985; Webber, 1988). The Yu-Cheng incident affected around 2,000 people (Rogan et al., 1988) the majority of whom were students and factory workers (Hsu et al.,
Blood PCB levels ranged from 3 to 1,156 ppb in exposed Yu-Cheng patients (Hsu et al., 1984).

Patients of the two poisoning episodes suffered from a wide range of symptoms such as acnelike eruptions, follicular cysts, eye discharge, nail deformity and pigmentation, skin pigmentation, dryness of skin, cyst formation, and hair loss (Kuratsune et al., 1972; Lu & Wong, 1984; Urabe & Asahi, 1984). Chloracne (a severe form of acne) and dermatitis were the two most notable negative health effects related to PCB exposure (Webber, 1988). A number of Yu-Cheng babies of exposed mothers were stillborn while those born suffered from hyperpigmentation (43%), eye discharge (30%), skin abscesses (22%), and bronchitis during the first 6 months (24%) (Rogan et al., 1988). A follow-up study investigating the negative effects of PCBs on the Yusho patients after 35 years found a decrease in symptoms such as acneform eruptions, dermal pigmentation, and eye discharge. However, enzyme and hormonal problems were still evident (Masuda, 2005).

In addition, neurodevelopmental studies have also been conducted with the victims. In one study 128 children (average age 32 months) born to exposed Yu-Cheng mothers and 115 matched controls (average age 31 months) were investigated. Parental reports, standardized tests, and neurological examinations were conducted. Exposed children exhibited developmental delays on 32 out of the 33 developmental milestones investigated in the study compared to the control group (Rogan et al., 1988).

Cognitive tests were also given to the same group of exposed Yu-Cheng children (Yu, Hsu, Gladen, & Rogan, 1991). The Bayley Scale of Infant Development was administered on three occasions before the children were 2.5 years of age. Compared to a control group, the Yu-Cheng children scored significantly lower on both mental (100 vs. 106) and psychomotor
indexes during the first testing session. During the same session, two and a half to 6 year olds scored 4 points lower on the Stanford-Binet IQ test (85 vs. 89), children over 6 years of age scored 7 points lower on the performance IQ section of the Wechsler Intelligence Scale for Children-Revised (90 vs. 97) and 4 points lower on the WISC’s full IQ scale (84 vs. 88). Lower scores were also obtained during the follow-up sessions for all three tests.

Although many of the symptoms were initially linked to PCBs in the rice oil, it is now accepted that PCDFs (polychlorinated dibenzofurans), PCDDs (polychlorinated dibenzodioxins), and PCQs (polychlorinated quaterphenyls), which were also present and are far more toxic than PCBs, were responsible for many of the symptoms in these patients because such deficits have not been found in workers occupationally exposed to similar and/or higher levels of PCBs (Ikeda, 1996; Seegal, 1996; Webber, 1988). Nonetheless, the two episodes raised public concern over possible human health effects of PCBs.

Low levels of exposure: Human cohort studies. Concerns over PCB toxicity following the Yusho and Yu-Cheng episodes motivated numerous investigations of PCB effects in various countries to examine the physical, sensory, motor, neurodevelopmental, cognitive, behavioral, and attentional effects of PCBs. These include the North Carolina (e.g., Rogan & Gladen, 1991), Michigan (e.g., Jacobson & Jacobson, 1996), Oswego (e.g., Stewart et al., 2003b), Faroe Islands (e.g., Grandjean et al., 2001), German (e.g., Winneke et al., 1998), and Netherlands (e.g., Koopman-Esseboom et al., 1996) studies. The Michigan, Oswego, and the Faroe Islands cohorts involved children born to mothers who had consumed contaminated fish, while the Netherlands, German, and North Carolina studies involved children from the general population (Ribas-Fito et al., 2001; Schantz, Widholm, & Rice, 2003). Summaries of
findings for these individual studies have been reported in detail elsewhere (Boucher, Muckle, & Bastien, 2009; Ribas-Fito et al.; Schantz et al.) and are briefly summarized below.

It is difficult to make comparisons between the human studies mainly because of the variations in the specimens used in the different cohorts to measure PCB exposure (i.e., cord blood level, maternal blood level, participant’s blood level, maternal milk levels, fish consumption), the different chemical analytical methods used, the different methods of calculating PCB levels, and the choice of congeners investigated. Studies have also used different neurodevelopmental outcome measures and have tested children at different ages.

In comparing studies, one must also keep in mind the different levels of exposure in the various studies. For example, PCB levels in the Faroe Islands cohort is about 3 to 4 times higher than other cohorts, and exposure levels in recent US studies are about one-third lower than earlier US studies (Longnecker et al., 2003). Nonetheless, there are some parallels among the different cohorts in their findings.

Sensory and motor effects. For a few of the cohorts, the relationship between prenatal PCB exposure and behavior during infancy using the Brazelton Neonatal Behavioral Assessment Scale (NBAS) (Jacobson et al., 1984b; Lonky et al., 1996; Rogan et al., 1986; Stewart et al., 2000) was investigated. According to Stewart et al., the NBAS is a measure of motor behavior, reflex, and interactiveness in newborns. In the Michigan cohort, newborns showed weaker neuromuscular functioning and reflexes. They also exhibited greater motor immaturity (more startles), hypoactive reflexes, and poorer lability of states. Caution is warranted because deficits were associated with maternal fish eating and not PCB cord levels (Jacobson et al.). In the Oswego cohort, newborns in the high exposed group (based on maternal fish consumption) scored lower on the reflex, autonomic, and habituation sections
of the NBAS (Lonky et al.). A second study revealed that only highly chlorinated PCBs were related to NBAS scores for autonomic and habituation sections. No effects were found for reflexes (Stewart et al.). In North Carolina, infants with higher PCB concentration in maternal milk displayed hypotonicity and hyporeflexia (Rogan et al.).

In recent years, cord PCBs have also been negatively related to the NBAS in infants in New Bedford, Massachusetts where the negative relationship was with the attentional measures of the scale (Sajiv et al., 2008). Another study used the Bayley Scales of Infant Development (BSID-II) Behaviour Rating Scales (BRS) to investigate the behavior of 11 month olds from Nunavik (Canada). The relationship between simulated PCB 153 levels and infant attention and activity was examined. Prenatal exposure was related to inattention and postnatal exposure was related to activity level using the simulated PCB 153 (Verner et al., 2010).

It is important to note that studies conducted using older children have shown no relationship between prenatal PCB exposure and motor function in children ages 4 to 7 (Després et al., 2005; Grandjean et al., 2001; Jacobson et al., 1990b) except in the Netherlands where prenatal PCB exposure was negatively related to the MSCA (McCarthy Scales of Children’s Abilities) Motor Scale at 6.5 years of age (Vreugdenhil, Lanting, Mulder, Boersma, & Weisglas-Kuperus, 2002).

Cognition and memory effects. A growing body of research from the cohorts has investigated the relationship between low levels of PCBs and neurodevelopmental effects such as cognitive functioning and memory in children (Darvill et al., 2000; Jacobson & Jacobson, 1996; Jacobson, Fein, Jacobson, Schwartz, & Dowler, 1985; Patandin et al., 1999; Stewart et al., 2003b; Walkowiak et al., 2001; Winneke et al., 1998), including the
participants in the present study when they were adolescents (Newman et al., 2006, 2009). Although there are few studies that have investigated PCBs in adults, some have shown decrements in learning and memory evident in adulthood (Haase, McCaffrey, Santiago-Rivera, Morse, & Tarbell, 2009; Schantz et al., 2001).

The Bayley Scales of Infant Development have been frequently used as an instrument to measure mental and psychomotor development among infants. In general, prenatal PCB exposure has been linked to a decreased Bayley Psychomotor Development Index (PDI) (Gladen et al., 1988; Rogan & Gladen, 1991) which is a measure of gross and fine motor performance (Boucher et al., 2009). Negative associations were found at both 6 and 12 months of age (Gladen et al.) and at 18 and 24 months of age (Rogan & Gladen) in North Carolina. However, in Michigan no relationship was found at 5 months of age (Jacobson, Jacobson, & Fein, 1986) and in the Netherlands the negative relationship observed between in utero PCB exposure and PDI at 3 months of age was no longer observed at 7 and 18 months. No relationship was found between perinatal PCB exposure and the Mental Development Index (MDI) at 3, 7, or 18 months of age (Koopman-Esseboom et al., 1996). In Germany, a negative relationship was observed between maternal milk PCB concentrations and the Bayley Scales of Infant Development Mental and Motor scores at 7, 18, and 30 months of age. Moreover, PCBs have been inversely related to the Mental Development Index (MDI) only in Germany (Walkowiak et al., 2001; Winneke et al., 1998). At 42 months of age a significant negative relationship was observed between breast milk PCBs and children's scores on the mental processing index of the Kaufman-ABC (Walkowiak et al.).

In the Netherlands, cognitive assessments were conducted using the Dutch version of the Kaufman Assessment Battery for Children (K-ABC) and the Reynell Developmental
Language Scale (RDLS) at 42 months of age. Prenatal PCB exposure was related to significantly lower scores on the K-ABC. A negative but nonsignificant relationship was found for the verbal comprehension scale of the Reynell Developmental Language Scale (RDLS) (Patandin et al., 1999).

Moreover, in Michigan there was a significant relationship between prenatal PCB exposure and WISC-R (Wechsler Intelligence Scales for Children-Revised) full scale and verbal IQ with the greatest effect on verbal IQ scores at age 11 (Jacobson & Jacobson, 1996). Whereas, in Faroe Islands, there was no association between cord PCB levels and WISC-R at age 7 (Grandjean et al., 2001).

Cognitive development was measured using the McCarthy Scales of Children’s Abilities in the Oswego cohort at 38 and 54 months of age. Prenatal PCB exposure was related to deficits in McCarthy scores at 38 month of age but the relationship was no longer evident at 54 months of age (Stewart et al., 2003b). However, in North Carolina, there was no significant relationship between prenatal and postnatal PCB levels and the McCarthy Scales of Children’s Abilities at 3, 4 and 5 years of age (Gladen & Rogan, 1991).

Memory and cognitive functioning among the various cohorts have been assessed by a number of different measures with various age groups and exposure situations. These factors can explain some of the differences in findings among the studies. Nonetheless, human studies investigating the relationship between low level exposure to PCBs and cognition, while not always consistent, tend to show that prenatal exposure affects memory and cognitive functioning.

According to Sajiv et al. (2008), visual recognition memory is an early signal for attention. Effects of prenatal PCB exposure on this domain have been investigated using the
Fagan Test of Infant Intelligence. A negative association has been found between prenatal PCB exposure and visual recognition memory in 6 and 12 month olds in Oswego (Darvill et al., 2000) and in 7 month olds in Michigan (Jacobson et al., 1985) but not for 7 month olds in Germany (Winneke et al., 1998). In Michigan, postnatal PCB exposure was not related to visual recognition memory (Jacobson et al.) in 7 month olds.

**Attention**

Attention is a complex multidimensional construct that plays an important role in academic and school functioning. It has been investigated by cognitive psychologists since the 1950’s (Pashler, 1998). It involves both the selection of information and on-task concentration (Wells & Matthews, 1994). The Early Selection Theory of Attention was developed by Broadbent in 1958. According to Broadbent (1958, 1971) attention was a single, limited capacity system where some information passed and was processed by higher order cognitive processes while other information that was not attended to was screened out. For Broadbent, attention was a filter-based-system. Later filter theories of attention (Deutsch & Deutsch, 1963) argued that the filter is not at the sensory level and that all information is analyzed and passed on to higher order processing areas. However, these areas were not defined. More recent theories have focused on anatomical aspects of attention. Mirsky and colleagues’ (1987) anatomical model of attention divides attention into four factors - sustain, shift, focus–execute, and encode. Next, they used experimental and clinical data to link each factor to a given brain area. However, more studies are needed to validate the model.

**Brain structure and attention.** The frontal lobe contains the prefrontal cortex (Kalat, 2009) which is the executive center of the brain that is responsible for regulating attention and impulsive behavior (Barkley, 2000). According to Sullivan and Brake (2003), ADHD
partly results from deficits in the dopaminergic system in the prefrontal cortex of the brain. Problems with this region play a role in the symptoms of ADHD including problems with drive (the ability to do what is needed), sequencing (the working memory’s ability to deal with information logically regardless of the distractions the individual faces), and the executive control. Individuals with poor executive control may be impulsive, distractible, and have problems completing tasks (Doyle, 2006). Furthermore, anatomical theories of attention have also linked the frontal lobe and the prefrontal cortex to attentional processes (Mirsky, 1987). According to Mattes (1980) frontal cortex dysfunction is fundamental to hyperactivity.

**Attention and cognitive tasks.** Attention plays an important role in memory and cognitive functioning and thus is important for school achievement and performance. A person cannot learn new information without it (Boucher et al., 2009; Carpenter et al., 2002; Kindlon, 1998). Also, in order to analyze information, a person must be able to shift attention, and to reason must be able to sustain attention (Kindlon).

Many cognitive and academic tasks require a certain level of attention on the part of the learner. Research shows a relationship between concentration/attention problems and behavioral difficulties (Kellam et al., 1991; Rebok, Hawkins, Krener, Mayer, & Kellam, 1996) and poor academic achievement (Gordon, Mettelman, & Irwin, 1994; Kellam et al.; Rowe & Rowe, 1992).

Attention also has an important role in executive functioning. The term executive function is an umbrella term that refers to a set of “central control processes in the brain that connect, prioritize, and integrate operation of subordinate brain functions” (Brown, 2000, p. 10). Executive functions activate, organize, integrate, and manage other brain processes of
the individual and allow improved adaptation of the individual to the demands of a the task at hand (Brown). These central processes are needed for goal-directed behaviors such as goal orientation and planning, organization and prioritization, flexibility, and self regulatory processes such as self monitoring (Meltzer, 2007). According to Boucher et al. (2009), attention and executive function impairments can indirectly affect cognitive functioning which depends on these processes.

According to Barkley (2000), executive function includes actions taken by self-regulated individuals toward their future goals. These actions include response inhibition to control impulses, nonverbal working memory which enables a person to remember events, verbal working memory which allows the individual to reflect and question what is happening, self-regulation of motivation and emotion which involves intrinsic motivation and the ability to control emotions, and lastly self-directed play in order to analyze and synthesize what is happening. In short, executive function plays a key role in many academic and life functions. The load on executive function increases as a child grows older and reaches late adolescence and early adulthood because of the increasing need to deal with more complex tasks independently (Brown, 2000). Studies show that children with ADHD have problems with their executive functions such as planning and organization (Grodzinsky & Diamond, 1992) which are skills related to the prefrontal cortex (Clark, Prior, & Kinsella, 2000). Furthermore, these children are more likely to have problems with school achievement (Barkley et al., 1990; Fischer, Barkley, Edelbrock, & Smallish, 1990).

**Subtypes of attention.** Attention is typically divided into four major subtypes: selective attention or focused attention, divided attention, shifting attention, and sustained attention. Selective or focused attention is the ability to select and focus on the relevant
stimuli from the environment and a deficit in this domain leads to distractibility. Divided attention allows one to work with more than one stimulus concurrently, while shifting attention is the ability to switch attention between two or more stimuli. Lastly, sustained attention is the ability to maintain attention over time (Bedi, Halperin, & Sharma, 1994; Young & Bramham, 2007).

The term vigilance is also discussed in the literature of sustained attention and was first used by Mackworth in the 1950s. It is defined as “a state of readiness to detect and respond to certain specified small changes occurring at random time intervals in the environment” (Mackworth, 1957, pp. 389-390). Like attention, vigilance is also a multidimensional construct which includes “level of vigilance” and “vigilance decrement” (Parasuraman, 1984, p. 244). The first one deals with the overall level of performance and is regulated by arousal. The second is a decrease in a person's ability to detect infrequently presented signals over time on a given task (Parasuraman).

According to Mackworth (1957), there are two major factors that affect the loss of vigilance. The first factor is the “frequency of signal” (p. 390); signal detection increases with an increase in the frequency of signals presented in a given time. The second factor includes the “inter-signal interval” (p. 390); irregular unpredictable signals result in lower detection rates.

*Measures of attention.* Different measures have been used to examine vigilance and sustained attention. Behavior and attention have been measured via both rating scales and computerized vigilance tasks. A common approach has been the use of teacher and parent rating scales such as the Child Behavior Checklist (CBCL) (Achenbach, 1986), the Conners’ Teacher Rating Scale (CTRS) (Conners, 1990), the Conners Parent Rating Scale (CPRS)
(Conners), the Home Situations Questionnaires (HSQ) (Barkley, 1987), and the Attention Deficit Disorders Evaluation Scale (ADDES) (McCarney, 1995).

Although rating scales are important components of the assessment process they are not objective and thus are subject to distortion. For example, Schachar, Sandberg and Rutter (1986) showed that as oppositional behavior increased, teacher rating scales of inattentive behavior and hyperactivity became more inaccurate. Also, teachers tend to rate boys as having more symptoms than girls and furthermore, environmental factors such as class size also influenced teachers’ perceptions in the identification of ADHD students (Havey, Olson, McCormick, & Cates, 2005)

An alternative method of measuring attention and vigilance, and one that is more objective, is the use of computerized vigilance tasks (Riccio et al., 2001). One version involves the Conners’ Continuous Performance Test (CPT) which is an objective measure of impulsivity and inattention (Conners, 2000) and was originally designed to measure these domains in brain-damaged patients (Rosvold et al., 1956). The CPT has also been used for ADHD evaluation because it measures inattention and impulsivity which are the underlying constructs of ADHD (APA, 2000; Conners, 2000). Unlike other tests, the CPT is not cognitively challenging because it only requires the test taker to make a response to a given stimulus (Jacobson et al., 1992). There are several formats for the CPT, the most common of which is the X-type CPT.

The X-type CPT is a visual vigilance computerized test in which the individual needs to respond to certain target letters and to withhold responses to non-target letters. Errors of omission are the number of times the target letters are missed; errors of commission occur when an incorrect response is made (Conners, 2000). Inattention is often operationalized as
an increase in errors of omission while impulsivity is reflected in an increase in errors of commission (Conners).

The CPT has also been used to investigate inattention and impulsivity in children and young adults with ADHD. Compared with children in control groups, children with ADHD commit more errors of omission and commission on the CPT (Harper & Ottinger, 1992; Hooks, Milich, & Lorch, 1994). Similar results have been found in adults. For example, more errors of omission and errors of commission have been observed in an ADHD adult group as compared to the control group (Barkley, Murphy, & Kwasnik, 1996). Boucher et al. (2009) encourage researchers to use the CPT when investigating the toxic effects of PCBs because the test has been “sensitive” (p. 14) to PCB effects. For example, PCB effects have been found using the CPT in Oswego (Stewart et al., 2003a, 2005), Michigan (Jacobson & Jacobson, 2003), Netherlands (Vreugdenhil et al., 2004a), and Faroe Islands (Grandjean et al., 2001).

Factors affecting computerized vigilance performance. A large number of studies has been conducted to investigate the various factors that influence an individual’s performance on computerized attention tasks. Nieuwenstein, Aleman, and de Haan’s (2001) meta-analysis looked at schizophrenic patients’ performance on the CPT. Significant relationships were found between CPT performance and schizophrenic symptoms across studies.

When included in a factor analysis, CPT performance loads on academic achievement (Campbell, D'Amato, Raggio, & Stephens, 1991) and has been used to identify low academic readiness in kindergarteners (Edley & Knopf, 1987). Eliason and Rishman (1987) showed that children with learning disabilities made significantly more errors of omission but not
errors of commission than the control group. Furthermore, a person’s ability to cope with boredom is related to improved performance (Hamilton, Haier, & Buchsbaum, 1984).

Levy (1980) investigated gender differences using the X-CPT in children between 3 and 7 years of age and found no significant gender differences for omission and commission scores. However, other researchers have found some gender differences. For example, Giambra and Quilter (1989) found that women had slower response times but that there were no differences in their detection accuracy.

Age and social class have been found to be related to CPT performance. Low SES groups tend to perform poorly on measures of attention (Norman & Breznitz, 1992). Levy (1980) found that children from upper SES performed better on a CPT task at a younger age than those in the lower SES group. Moreover, Gordon and Mettelman (1988) found a relationship between the father’s SES and commission scores and between maternal SES and the total number of correct scores. Age-related differences have also been observed in CPT performance. The effect of age on CPT performance was assessed in 32 adults ages 19 to 82 (Mani, Bedwell, & Miller, 2005). Errors of commission significantly increased with age.

Certain substances have also been found to affect performance on the CPT. Medications such as benzodiazepines (Golombok, Moodley, & Lader, 1988) have hindered performance while caffeine (Lieberman, Wurtman, Emde, Roberts, & Coviella, 1987) and central nervous system stimulants such as methylphenidate have improved performance (Aman, Kern, McGhee, & Arnold, 1993). Furthermore, significant relationships between prenatal alcohol exposure and errors of omission and commission have also been observed (Streissguth et al., 1986; Streissguth et al., 1984). Prenatal tobacco exposure is also related to increased omission and commission errors (Streissguth et al., 1984).
Lastly, a few studies have investigated the relationship between neurotoxic exposure and CPT performance. A negative dose-response relationship has been reported between CPT performance and ethylene oxide exposure (Estrin et al., 1987) and styrene exposed individuals (Tsai & Chen, 1996).

Attention Deficit Hyperactive Disorder (ADHD). The DSM-IV TR (Diagnostic and Statistical Manual of Mental Disorders-Fourth Edition, Text Revision) recognizes impaired attention as Attention-Deficit Hyperactivity Disorder. Inattention, hyperactivity, and impulsivity are the primary symptoms of the disorder. It is estimated that about 3% to 5% of school-aged children in the United States are affected by ADHD (APA, 2000). Although hyperactivity tends to improve as a person grows older, attentional problems tend to persist over time and become more problematic as in adulthood (Resnick, 2000).

There are three types of ADHD: the Predominantly Inattentive type, the Predominantly Hyperactive-Impulsive type, and the Combined type. Inattentive symptoms include such behaviors as “difficulty sustaining attention in tasks,” (APA, 2002, p. 85) “difficulty organizing tasks and activities” (APA, p. 85), and being “easily distracted by irrelevant stimuli” (APA, p. 86). The hyperactive symptoms include such behaviors as fidgeting and restlessness, while symptoms of impulsivity include a tendency to be impatient, having problems waiting turns, and tendency to interrupt others (APA).

In order to be diagnosed with ADHD, a person must have the disorder for at least six months, the symptoms must appear before the age of seven, and should be apparent in at least two environmental settings (i.e. home, school, and/or work). The individual must have six or more of the nine symptoms listed under inattention and/or six or more of the nine symptoms listed under hyperactivity-impulsivity (APA, 2000).
In general, children with ADHD tend to suffer academically. In one study of hyperactive children between 4 and 12 years of age, 46.3% were suspended from school, 29.3%, were retained a grade level, 10.6% were expelled from school, 9.8% dropped out of school, 32.5% were in special education for learning disability, and 35.8% had behavioral disorder classes compared to the matched control group (Barkley et al., 1990). In their 8 year follow-up study (Fischer et al., 1990), this research team found that the hyperactive children (N=123) showed poorer sustained attention and continued to have impaired academic achievement, exhibited more off-task, and vocal behavior as compared to the matched control group. As a result, they concluded that hyperactive children are chronically impaired in such domains as academic achievement.

Adults with ADHD tend to have lower educational achievements, marital and employment problems, and use more illegal substances (Murphy & Barkley, 1996). They also report higher rates of repeating grades, tutoring, and special education placement (Biederman et al., 1993). For example, 16-39.5% of them have repeated a grade (Barkley et al., 1996; Murphy & Barkley), 36% have received extra tutoring in school (Biederman et al.), 28% have received special education services, and 12% have graduated from college (Barkley et al.). According to the Murphy and Barkley study, adults with ADHD were more likely to be fired from their jobs (52.9% vs. 30.8%), quit a job (47.9% vs. 16%), have chronic employment problems (76.7% vs. 57.1%), have dropped out of college (53.5% vs. 34.5%), abused illegal drugs (39.5% vs. 13.8%), and be arrested (33.7% vs. 17.9%) than the adults in the control group.

Some researchers have found relationships between PCB exposure and ADHD symptoms in both animals (Holene et al., 1998; Rice, 2000) and young children (Jacobson &
Jacobson, 2003; Stewart et al., 2003a, 2005). Therefore, investigating the relationship between blood PCB levels and symptoms of ADHD, such as lack of attention and impulsivity, in young adults seems appropriate.

Impulsivity

As stated above, impulsivity is a characteristic in some forms of ADHD. It is also found in other disorders such as conduct disorder and antisocial personality disorder (APA, 2000). Impulsivity is measured using rating scales, neuropsychological tests, and computerized vigilance tasks. The Child Behavior Checklist (Achenbach, 1986), the Conners’ Rating Scales (Conners, 1990), the Circle Tracing Task (Bachorowski & Newman, 1985), the Stroop Word-Color Test (Golden, 1978), and the CPT (Conners, 2000) are a few common measures of impulsivity.

Frosch (1977) defined impulsivity as the “[…] welling-up of a drive toward some action that usually has the qualities of hastiness, lack of deliberation, and impetuosity” (p. 296). According to Coles (1997) impulsivity is related to the speed that it takes for an individual to react in a given situation.

There are two types of impulsivity: functional impulsivity and dysfunctional impulsivity. In functional impulsivity the impulsive act is beneficial because the individual has quickly thought and made a decision whereas in dysfunctional impulsivity the individual takes actions without considering the negative consequences of his or her actions. Here, not only the act but the situation in which the impulsive act has occurred is important (Dickmans, 1990). There are also two distinct models of impulsivity: the reward-discounting model (inability to wait for reward) and the rapid-response model (responding without assessment) (Swann, Bjork, Moeller, & Dougherty, 2002)
Studies have linked frontal lobe abnormalities to impulsivity in both humans and primates. For example, in one study gamblers with prefrontal lesions were not influenced by the future consequences of their actions and were mainly influenced by the immediate consequences of their actions (Bechara, Tranel, & Damasio, 2000). Furthermore, a decrease in frontal lobe activity has been observed in gamblers (Goyer et al., 1999). In animals, Cardinal et al. (2001) found that rats with frontal brain lesions tended to chose small or poor rewards that were available to them immediately rather than to wait and obtain larger rewards. In humans, self-controlled individuals are influenced more with delayed reinforces than impulsive individuals (Evenden, 1999). In short, frontal cortex abnormalities are associated with various aspects of impulsivity such as not being able to delay or inhibit acting on an impulse.

Effects of PCBs on Attention, Behavior, and Impulsivity

Both animal and human studies have been conducted in order to investigate the effects of PCBs on attention, behavior, and impulsivity. Animal models have been used to study PCBs neurotoxicology because they are cost effective, less time consuming and allow experimental testing that is not possible with humans because of ethical constraints. Animal studies allow the researcher to monitor developmental changes on selected neurodevelopmental endpoints in order to investigate dose-response relationships in critical periods of development (Branchi, Capone, Alleva, & Costa, 2003; Venerosi, Calamandrei, & Alleva, 2002). It also allows the study to be done in a short period of time because animals mature faster. For example a rodent reaches puberty in 35 days and sexual maturation in 60 days (Venerosi et al.). As a result, animal studies have been used in order to hypothesize the relationship between PCBs exposure and potential outcomes in humans.
In human studies, on the other hand, it is important to investigate effects with various age groups because in past studies, different findings on the same outcomes have been observed with development (Boucher et al., 2009). One reason can be the fact that certain areas of the brain, such as the frontal lobe, mature late and continue to grow through late adolescence (Segalowitz & Davies, 2004) making it important to investigate effects later in development. Furthermore, processing speed (efficient processing), response inhibition (ability to filter out distracters), and working memory (ability to maintain and manipulate information) all continue to improve as an individual grows older; mature adult level performance for these three domains begins at about 15, 14 and 19 years of age respectively (Luna, Garver, Urban, Lazar, & Sweeney, 2004).

According to Boucher et al. (2009), studies show a decrease in executive functions such as planning (Jacobson & Jacobson, 1996; Vreugdenhil et al., 2004a), working memory (Jacobson & Jacobson, 2003), set shifting (Jacobson & Jacobson, 2003), and response inhibition (Jacobson & Jacobson, 2003; Stewart et al., 2003a, 2005, 2006) with an increase in PCB exposure. Also PCBs have been associated with attentional deficits in animals (Levin, Schantz, & Bowman, 1988; Schantz, Levin, Bowman, Heironimus, & Laughlin, 1989) and humans (Jacobson & Jacobson, 2003; Vreugdenhil et al., 2004a; Vreugdenhil, Van Zanten, Brocaar, Mulder, & Weisglas-Kuperus, 2004b). These studies suggest that there may be a relationship between PCBs and attention, behavior, and impulsivity making it important to investigate this relationship further. In a recent review conducted by Eubig, Aguiar, and Schantz (2010), the authors also conclude that PCB exposure is related to deficits in such attention and executive functions as response inhibition and vigilance in both animals and
humans. These authors point out that although these deficits have been found in children with ADHD, the role of PCBs in these relationships has not been investigated.

**Animal studies.** A wide variety of PCBs effects have been found in animal studies. For example, PCBs alter thyroid (Goldey et al., 1995a; Morse et al., 1993) and dopamine (Seegal et al., 1994) levels in animals. Tilson, Jacobson and Rogan's (1990) review of different animal studies found relationships between PCB exposure and learning difficulties, changes in activity levels (increase or decrease in activity levels), and a slower development of reflexes.

Generally, prenatal PCBs exposure has resulted in an increase in hyperactivity and motor activity in mice (Agrawal et al., 1981; Carpenter et al., 2002; Chou et al., 1979; Daly et al., 1998; Tilson et al., 1979) and monkeys (Bowman et al., 1978). In an early animal study, Bowman et al. used offspring of female adult monkeys that were fed two different levels of Aroclors, and four control monkeys. The chronic low level PCBs exposure of the subjects in the study is typical of the most common form of human exposure. The monkeys were tested on 11 tasks. Hyperlocomotor activity was positively correlated with PCBs levels at both 6 and 12 months of age. The same animals were tested again at 44 months of age and PCBs-exposed monkeys hyperactive at 6 and 12 months of age were found to be hypoactive at 44 months (Bowman & Heironimus, 1981). In another study, Chou et al. found increased spinning syndrome in litters of mice dosed with 32 mg/kg/day of 3, 4, 3', 4'-tetrachlorobiphenyl on days 10 through 16 of gestation.

Female and male rats prenatally exposed to PCBs through ingestion of contaminated fish from waters close to General Motors Superfund site near the St. Lawrence River in New York State were more hyperactive and impulsive when compared to an unexposed control.
group (Carpenter et al., 2002). Similarly pre and postnatal exposure to Lake Ontario salmon produced hyperactivity in rats (Daly et al., 1998).

Adult animals have also been investigated. In one study adult mice whose mothers were exposed to 3, 4, 3', 4'-tetrachlorobiphenyl during gestation showed neurobehavioral syndromes such as stereotypic circling, head bobbing, and hyperactivity at 35 and 65 days of age (Tilson et al., 1979). In another study mice exposed to 3, 4, 3', 4'-tetrachlorobiphenyl in utero had high motor activity and decreased levels of dopamine at one year of age (Agrawal et al., 1981). Another study of rats exposed to PCB 95 during gestation and lactation showed that they had normal activity levels as juveniles but were hypoactive when retested as adults (Schantz, Seo, Wong, & Pessah, 1997). Perinatal PCB153 exposure in rats resulted in a non significant increase in aggressiveness in males (Haave et al., 2011).

The relationship of behavior to postnatal exposure to PCBs has also been investigated with animals. In one study, adult robins showed heightened activity patterns as compared to the control group after being fed 3 to 11 worms injected with 5 µg of Clophen A50 daily (Ulfstrand et al., 1971). Furthermore, adult rats exposed to PCBs during puberty were 1.5 times more overactive in pressing rates than the unexposed control group (Berger et al., 2001).

Other studies have found impairment in attention in relation to PCB exposure. For example, Schantz and her colleagues have found that monkeys exposed to commercial PCBs during gestation and lactation showed impairments on a discrimination-reversal learning task (Schantz et al., 1989). Holene et al. (1998) found that rats exposed to PCB congeners 153 and 126 through mother’s milk showed increased motor activity and attention deficits similar to spontaneously hyperactive rats (SHR) which is an animal form of ADHD.
PCB exposure has also resulted in impairments in response inhibition. For example, Rice (1997a) found that postnatal exposure of monkeys from birth to 20 weeks with a PCB mixture similar to that found in human breast milk resulted in behavioral impairments and displayed impairments in learning and perseveration at four years of age. The monkeys were also unable to inhibit inappropriate responding. Bushnell and Rice (1999) investigated adult rats exposed to PCB 126 and found increased false alarm rate and reduced accuracy on tasks requiring attention. However, in another study Bushnell and colleagues did not find any relationship between PCB exposure and attention in adult rats (Bushnell et al., 2002).

Animal studies cannot provide the exact picture in humans because of physiological and metabolic differences between animals and humans (Ross, 2004). Therefore, human studies are essential. The large body of animal studies showing attentional and neurobehavioral effects following both prenatal and postnatal exposure to PCBs from early development to adulthood highlights the need to study these effects in humans including adults.

*Human studies.* Despite the large body of research looking at the physical and cognitive effects of PCB exposure, fewer studies have investigated “specific behavioral processes” (Stewart et al., 2005, p. 271) such as attention in humans even though in animal studies, ADHD like effects have been found in rats and monkeys exposed to PCBs (Holene et al., 1998; Rice, 2000). Because of this, researchers in this area suggest that “more research needs to be done” (Darvill, Lonky, Reihman, & Daly, 1996, p. 265).

To date, neurobehavioral and sustained attention effects have been studied in children in Taiwan (Chen et al., 1994; Chen & Hsu, 1994; Lai et al., 2002), Michigan (Jacobson & Jacobson, 2003; Jacobson et al., 1990a, 1992), Oswego (Stewart et al., 2003a, 2005), Faroe
Islands (Grandjean et al., 2001), Netherlands (Vreugdenhil et al., 2004a, 2004b), Massachusetts (Sajiv et al., 2008, 2010), and Nunavik (Canada) (Verner et al., 2010).

Investigating such relationships in human studies is difficult because, unlike the situation in animal studies, researchers cannot for ethical reasons control for confounding variables by random assignment of participants to exposed and control groups. Therefore these variables need to be addressed statistically. Nonetheless, several human studies conducted show a relationship between PCB exposure and attention and impulsivity. Some of these studies have found a relationship between PCBs and behavior and attention among children (Chen et al., 1994; Chen & Hsu, 1994; Grandjean et al., 2001; Jacobson & Jacobson, 2003; Jacobson et al., 1990a; Lai et al., 2002; Sajiv et al., 2008, 2010; Stewart et al., 2003a, 2005; Verner et al., 2010; Vreugdenhil et al., 2004a, 2004b).

One of the first investigations in this area was conducted in Taiwan. Chen et al. (1994) studied Yu-Cheng children's behavior biennially from 1985 to 1991. They used a translated version of the Rutter’s Child Behavior Scale A, which measures problem behavior, and a modified version of Werry-Weiss-Peters Activity Scale, which measures activity level. The study examined 118 Yu-Cheng children ages 3 to 12 who had been prenatally exposed to PCBs with an equal number of controls matched on age, sex, neighborhood, maternal age, and socioeconomic status. Both questionnaires were completed by parents. The exposed children had scored 11% to 63% higher on problem behaviors on the Rutter Scale and had an activity score of 8% to 53% higher on the Werry-Weiss-Peters Activity Scale at each given age than the control group. Both effects persisted as the children aged.

From 1992 to 1995 a follow up study on the same group of children was conducted using the two behavioral tests: the Achenbach Child Behavior Checklist (CBCL) and the
Rutter Child Behavior Scale. Parents filled out both questionnaires. The exposed children scored about 3 points higher on the CBCL total score and similarly for the internalizing and externalizing subscales of the checklist. Furthermore, they scored 6 points higher on the Rutter Child Behavior scale which focuses on problem behavior (Lai et al., 2002) than the matched control group. The two studies clearly show a negative relationship between prenatal PCB exposure and behavior.

In another study, 27 Yu-Cheng children ages 7 to 12 with an equal number of controls matched on sex, age, residential area, birth order, and socioeconomic status were tested on an auditory test in which the subjects had to press a button when they heard the target tone. Each trial included 30 targets and 120 non targets (Chen & Hsu, 1994). This test has been found to differentiate between children with ADHD and controls (Lazzaro et al., 1997) and is a measure of concentration (Chen & Hsu). The Yu-Cheng children had more attentional problems than the control (Chen & Hsu).

The sustained attention of 226 4-year olds in the Michigan cohort was tested with a modified version of Catch the Cat which is a computerized vigilance test. The test is 12 minutes long with three 4-minute blocks in which the target (a cat) appears on one of three randomly selected windows of a house for 500 ms on a computer screen for 4 to 48 seconds. The cat appears a total of 14 times in each block. Distracters (an apple and a butterfly) also appear in the windows. The child is instructed to hit a key when the cat appears. PCBs were measured as cord PCBs and the child’s serum PCB. Exposure through breastfeeding was measured as PCB levels in maternal milk and weeks of nursing. The PCB congeners measured were Aroclors 1016 and 1260. Prenatal PCB exposure was not related to sustained attention (Jacobson et al., 1992). However, reduced activity was associated with serum body
burden PCB levels at age 4 as measured by the Activity Scale of the EAS Temperament Survey for Children (Buss & Plomin, 1984) filled by the mother and a 10-item Child Behavior Record from the Bayley Infant Behavior Record filled by the examiner (Jacobson et al., 1990a).

In a second study Jacobson and Jacobson (2003) investigated the relationship between prenatal PCB exposure, and attention and information processing, in 154 4-year olds and 148 11-year olds. PCBs were measured as cord and maternal serum, milk PCB levels, and serum PCB levels at age 4. The congeners used in the study were Aroclors 1016 and 1260. The study used three different forms CPT (the X-CPT, the AX-CPT, and an auditory-CPT) to measure sustained attention. Focused attention was measured by using a Digit Cancelation Test. A significant relationship was found between prenatal PCB exposure and an increase in errors of omission on the Digit Cancellation at age 11 which indicates lack of concentration. Prenatal exposure also resulted in more errors of commission in 11-year olds which is suggestive of poorer response inhibition or impulsivity (Jacobson & Jacobson).

Stewart et al. (2003a) tested 197 4.5-year olds in the Oswego cohort using the same Catch the Cat test that was used in the Michigan study (Jacobson et al., 1992). Umbilical cord blood was analyzed for the following persistent PCB congeners (170+190, 172, 174, 177, 179, 180, 183, 185, 187+181, 194, 195, 199, 203+196, 206). In contrast to the findings in Michigan where prenatal PCB exposure was not related to sustained attention (Jacobson et al.), the Oswego study found a relationship between higher cord blood PCB levels and an increase in errors of commission especially during later testing blocks (Stewart et al., 2003a). Of these participants, 182 children were tested again at 8 years of age using the Neurobehavioral Evaluation System (NES2) Continuous Performance Test and 183 children
were tested at 9.5 years of age using the Extended Continuous Performance Test (E-CPT).
However, valid NES2 data was available on only 174 of the children. Prenatal PCB exposure
was related to impulsive responding as measured by commission errors at both ages (Stewart
et al., 2005). In these studies prenatal PCB exposure was related to commission errors on
three different forms of CPT vigilance tasks at 4.5, 8, and 9.5 years of age.

Grandjean et al. (2001) investigated the relationship between PCBs and
neurobehavioral problems in 442 7-year old children in the Faroese birth cohort who were
exposed to seafood neurotoxicants. Cord PCB concentration was measured as the sum of
three PCB congeners (138, 153, and 180) multiplied by two. Attention was measured using
the reaction time on a modified version of NES2 CPT. In this test children had to press a
button every time they saw a cat in the 4 minute block. Cord PCB was associated with
attention as measured by an increase in reaction time.

Lastly, 104 9-year olds in the Netherlands cohort (Vreugdenhil et al., 2004a) were
administered a modified version of the Simple Reaction Time Test (SRTT). The test is a 6
minutes test, in which the child has to press a button every time a red square appears on the
computer screen. The test consists of 80 trials. PCBs were measured as the sum of four
congeners (118, 138, 153, and 180) in maternal plasma. The study used mean response time
(RT) as a measure of processing speed and sustained attention, and the variation of RT (SD)
as a measure of sustained attention. In this study, prenatal PCB exposure was related to
longer and more varied RTs. In a second study, 104 9-year olds completed an auditory
vigilance task in which children had to press a button when they heard the target tone. The
PCB exposure measure was the same as in the previous study. Longer latencies were
observed in children with more prenatal PCB exposure (Vreugdenhil et al., 2004b).
In a recent study, two studies have been conducted in Massachusetts. In the first study cord PCBs were negatively related to the attentional measures of the NBAS in 542 infants (Sajiv et al., 2008). In a second study, Sagiv et al. (2010) looked at the relationship between prenatal PCB exposure as the sum of cord PCBs 118, 138, 153, and 180, and behavior as measured by the Conners’ Rating Scale for Teachers (CRS-T) in 607 children ages 7 to 11 whose mothers lived close to a contaminated harbor in New Bedford. Higher PCB levels were related to Conners’ ADHD index.

The Bayley Scales of Infant Development (BSID-II) Behaviour Rating Scales (BRS) was used to investigate the relationship between simulated PCB 153 levels and infants’ attention and activity in Nunavik (Canada). The study included 168 participants. Prenatal exposure was related to inattention and postnatal exposure was related to activity level (Verner et al., 2010).

As previously stated, PCBs psychomotor effects have been found in infants (Gladen et al., 1988; Koopman-Esseboom et al., 1996; Rogan & Gladen, 1991; Winneke et al., 1998) but not during childhood (Després et al., 2005; Grandjean et al., 2001; Jacobson et al., 1990b). Because of this, Boucher et al. (2009) concludes that poor performance on vigilance tests that require physical response such as pressing the space bar as is the case in the CPT is more likely related to cognitive, attentional, and executive function problems and not related to motor problems.

Although it has been shown that there are higher concentrations of PCBs in breast milk than in maternal serum or cord serum, studies have found that prenatal PCB exposure is associated with more negative outcomes than exposure by lactation, such as lowered birth weight and smaller head circumference (Fein et al., 1984), visual recognition memory
(Jacobson et al., 1985), cognitive and intellectual impairments (Chen, Guo, Hsu, & Rogan, 1992; Jacobson & Jacobson, 1996; Lai et al., 1994; Patandin et al., 1999), delayed development (Guo et al., 1994), and behavioral problems (Lai et al., 2002). One reason for this can be the fact that neonates are exposed to low levels of PCBs on a continuous basis and the exposure is occurring during a critical time in development. Furthermore, even though the amount of exposure is small it is large in comparison to the size of the fetus (Jacobson et al., 1984a).

Past epidemiological studies show that PCBs cross the placenta and thus can affect the development of the fetus resulting in not only physiological effects but also cognitive, attentional, and behavioral effects in both animals and humans. Although prenatal exposure is associated with more negative outcomes than postnatal, effects have been found for both prenatal and postnatal exposure. Since some deficits disappear and others do not appear until later in development it is important to investigate such effects in different age groups in humans. Furthermore, even though animal studies can be used to hypothesize the relationship between PCBs exposure and various outcome measures in humans it is important to corroborate these findings in humans.

**PCBs and the Akwesasne Mohawk Nation**

The Mohawk Nation of Akwesasne is located along the St. Lawrence River. Because of their knowledge of the harmful effects of PCB exposure, the Akwesasne Mohawk community members became concerned about potential health effects of toxic exposure in their own environment which has been polluted by PCBs discharged by industries into their waterways. A National Priority Superfund site and two New York State Superfund sites are upstream of Akwesasne (DeCaprio et al., 2005). As a result, industrial effluent has
contaminated their local environment. Therefore, foods that are caught and harvested in the community have been contaminated by PCBs. Since the community utilizes locally caught fish, wildlife, and harvest for food, they are at risk for higher exposure levels.

Studies commenced in 1995 and are ongoing about various health effects of the exposure to PCBs and other environmental toxins. One set of studies (MAWBS) concerned psychological effects of PCBs on the cognition and attention of Akwesasne adolescents. Findings from these studies are summarized in Appendix A and are described below.

**MAWBS: Cognitive.** Cognitive functioning of the Akwesasne Mohawk adolescents has been measured by the Woodcock Johnson-Revised (WJ-R), the Test of Memory and Learning (TOMAL), and the Ravens Progressive Matrices (RPM). A negative relationship was found between a summative measure of those PCBs found in at least 50% of the participants ($\Sigma$PCB50%) and scores of Long Term Retrieval and Comprehension-Knowledge of the WJ-R, and TOMAL’s Delayed Recall (Newman et al., 2006).

In a second study, Newman et al. (2009) examined the relationship between four PCB congener groups (dioxin-like, non-dioxin-like, persistent, and low-persistent) and cognition as measured by Ravens Progressive Matrices, the Test of Memory and Learning, and the Woodcock Johnson-Revised Tests of Cognitive Ability. Dioxin-like PCBs were related to Ravens, TOMAL’s Delayed Recall, and WJ-R’s Long Term Retrieval scores, whereas non-dioxin-like PCBs were only related to TOMAL’s Delayed Recall and WJ-R’s Long Term Retrieval scores. Persistent PCBs were related to TOMAL’s Delayed Recall, WJ-R’s Long Term Retrieval, and WJ-R’s Auditory Processing whereas low-persistent PCBs were related to TOMAL’s Delayed Recall, WJ-R’s Long Term Retrieval, and WJ-R’s Comprehension-Knowledge.
**MAWBS: Attention.** Aucompaugh (2005) examined the relationship between PCB exposure and attention in the MAWBS using behavior rating scales. Adolescent blood PCB levels were not related to the inattentive-passive subscale of the Conners’ Rating Scale for Teachers (CRS-T) and the inattentiveness subscale of the Attention Deficit Disorder Evaluation Scale (ADDES) Home and School versions.

**The Present Study**

PCBs have been shown to affect multiple endocrine systems such as dopamine and thyroid levels which can affect arousal, activity level, and attention. Consistent with this possibility, animal (Agrawal et al., 1981; Berger et al., 2001; Bowman et al., 1978; Bushnell & Rice, 1999; Carpenter et al., 2002; Chou et al., 1979; Daly et al., 1998; Holene et al., 1998; Rice, 1997a; Schantz et al., 1989; Tilson et al., 1979; Ulfstrand et al., 1971) and human (Chen et al., 1994; Chen & Hsu, 1994; Grandjean et al., 2001; Jacobson & Jacobson, 2003; Jacobson et al., 1990a; Lai et al., 2002; Sajiv et al., 2010; Stewart et al., 2003a, 2005; Vreugdenhil et al., 2004a, 2004b) studies indicate that there may be a relationship between PCBs level and attention and impulsivity. Nevertheless, neither Jacobson et al. (1992), nor Aucompaugh (2005) with the Akwesasne participants when they were adolescents, found a relationship. Because of the contrary findings, the question is being addressed again, with the same Akwesasne participants who are now young adults, using a more objective measure of attention, namely the CPT.

The present study will examine a subset of data from the Young Adult Well-Being Study (YAWBS) which investigated various physical, health, behavioral, and cognitive outcomes of PCBs on a group of young adults whose mothers were likely to have been exposed to PCBs by eating local contaminated food before their pregnancy. As 10- to 16-
year olds, the young adults had previously participated in the Mohawk Adolescent Well-Being Study (MAWBS) which investigated the relationship between PCBs levels and their physical growth, sexual maturation, cognitive development and behavior.

In previous studies of the same participants, PCBs level was found to be related to measures of memory (Newman et al., 2006, 2009) but not to measures of behavioral attention as provided by the Conners’ Teacher Rating Scale and by the Home and School Versions of the Attention Deficit Disorder Evaluation Scale (ADDES) (Aucompaugh, 2005).

The present study will investigate the relationship between PCBs and sustained attention and impulsivity by using the X-CPT, a computerized measure. This will add to the findings of Aucompaugh (2005) gained from the same population. However, the current computerized measure will generate more objective behavioral data that were gained by the rating scales used in the Aucompaugh study.

There are two hypotheses:

1. That higher PCBs levels will be associated with higher omission errors (failing to respond to targets) which are indicative of inattention;

2. That higher PCBs levels will be associated with higher commission errors (responding to non-targets) which are indicative of impulsiveness.
Chapter 3

Method

Participants

The participants were young adults (aged 17 to 21) who participated in the Young Adult Well-Being Study (YAWBS) conducted at Akwesasne from 2000 to 2006. When aged 10 to 16.99 years, they had participated in the Mohawk Adolescent Well-Being Study (MAWBS) conducted from 1995 to 2000 and which looked at the relationship between PCBs levels and physical growth, sexual maturation, and cognitive development. Of the original 271 participants in the MAWBS, 154 were located who agreed to participate in the follow-up YAWBS. This second study of Mohawk culture, behavior, toxicant exposure and health, included performance on a computerized measure (CPT) of attention and impulsivity which is the focus of the present investigation. For the present study, 143 of the YAWBS participants took the CPT, and valid CPT scores were available for 141 of them (52 males and 89 females). The mean age of the YAWBS participants was 18.10 years (SD = 1.10 years, range 16.97-21.36 years). Of the 141 participants, 5 had taken ADHD medications during their high school years. The study was approved by University at Albany Institutional Review Board and was supported by the Akwesasne Task Force on the Environment. Written consent was obtained from participants prior to participation, and also from their parents if they were minors. All participants received gift certificates worth $50.

The participants were recruited from the earlier phase of the study (MAWBS) by research team members who were Akwesasne residents. Children were disqualified from participation in MAWBS if they had Fetal Alcohol Syndrome or Fetal Alcohol Effects, if they were a twin, if they had been hospitalized for brain injury, or if they had a serious
organic or psychological pathology (Newman et al., 2006), as all of these conditions could mask the effects of PCBs. Only one qualified child per family was accepted into the study in the MAWBS phase. All participants lived on or near the reserve. For the YAWBS, participants were disqualified if they were older than 21, were pregnant, had a child or had lactated in the past 6 months (Schell, Gallo, Ravenscroft, & DeCaprio., 2009).

In the late 1970s, the community’s concern over local environmental contamination grew. The presence of toxic chemicals in the environment resulted in warnings about local food consumption by the local tribal government and by the NYSDOH (New York State Department of Health). As a result, fish advisories were issued to warn pregnant and nursing mothers, infants and children under the age of 15 to refrain from eating any locally caught fish (Hoover, 2010).

Participants for the MAWBS and YAWBS were born to mothers who would likely have consumed local fish before the advisories and thus would have had higher PCB body burdens. As a result, the participants in this study would have been mainly exposed to PCBs prenatally through the placenta and postnatally through breastfeeding (Fitzgerald, Hwang, Bush, Cook, & Worswick, 1998) as infants, as well as through their own local food consumption as adults (Fitzgerald et al., 2004).

Setting

The study was conducted at the Mohawk Nation of Akwesasne, a Native American community with an estimated population of about 10,000 (Fitzgerald et al., 1998; Hwang, Yang, Fitzgerald, Bush, & Cook, 2001). It is located on the St. Lawrence River between upstate New York, Ontario and Quebec, and has an area of 28,000 acres. All participants lived on or near the reserve. The General Motors Central Foundry Division, a National
Priority Superfund site and two New York State Superfund sites (Reynolds Metal Company and Aluminum Company of America) are upstream of Akwesasne (Akwesasne Task Force on the Environment, 1997; DeCaprio et al., 2005; Hwang et al.). PCBs from industrial effluent have contaminated the local ecology and entered the Mohawks’ food chain. The community is concerned about the impact of industrial pollution on its members and environment because residents depended upon local fish and mammals for food. According to Fitzgerald et al. (2004), local fish consumption has been the primary route of exposure among Mohawk women.

**Procedures**

The current study is based on analysis of existing data gained from two research projects conducted between 1995-2000 (MAWBS) and 2000-2006 (YAWBS) at the Mohawk community of Akwesasne. All data gathering for both projects was done by individuals who were members of the Akwesasne community. Data collectors were trained and supervised by researchers at the University at Albany. Data collectors had no knowledge about the participants’ PCBs exposure levels.

**MAWBS.** The initial sample for the Mohawk Adolescent Wellbeing Study (MAWBS) was recruited in 1995. Detailed description of participant recruitment for the MAWBS has been published elsewhere (Schell et al., 2003) and will be briefly summarized here. Sample recruitment during the MAWBS phase involved creation of a detailed map of all households on the Mohawk Reserve by Mohawk field staff. Households were contacted to investigate eligibility. The study was explained and assents and consents were obtained from willing participants. For standardization purposes the oldest eligible child was selected from each
household. If the oldest child did not participate the next oldest eligible child was asked to participate (Schell et al.).

**YAWBS.** At the commencement of the Young Adult Wellbeing Study (YAWBS) in 2000, Akwesasne research team members attempted to recontact all MAWBS participants, and asked them to take part in the follow-up YAWBS phase of the study unless they were older than 21, were pregnant, had a child or had lactated in the past 6 months (Schell et al., 2009). Procedures were explained, and assents and consents were obtained from willing eligible participants who were located.

Participants were interviewed by an Akwesasne staff member who was trained and supervised by researchers at the university at Albany. Interviews concerned school functioning and their community functioning. The Conners’ Teacher Rating Scale (Conners, 1990) and the Attention Deficit Disorders Evaluation Scale (ADDES) School Version (McCarney, 1995) was completed for each participant by the teacher who had the most contact with the student. Teachers were paid $10 per student for providing this information. The Continuous Performance task (CPT) (Conners, 2000) was also administered by the interviewer in a quiet room in the homes of the participants using a laptop computer. The interviewer remained in the room to monitor the participant's continued engagement in the task. Information related to other aspects of the research project was gained by interview.

Detailed descriptions of procedures are given in previous publications (DeCaprio et al., 2005; DeCaprio et al., 2000; Schell & Gallo, 2010; Schell et al., 2009; Schell et al., 2003) by members of the research team and will be summarized here. A fasting blood sample was taken at first rising either at the participant's home or at the project office located on the Akwesasne Reserve by a trained Mohawk staff member. The participants were asked not to
eat any local food for 3 days before giving blood. They also could not eat or drink after 10 PM the night before blood collection. 20 mL of blood was collected for PCBs analysis by venipuncture and divided into two 10-mL red-top (no additive) Vacutainer tubes. Blood samples were first clotted at room temperature for 20 minutes prior to being centrifuged at 800 x g for 15 minutes. Aliquots of 5 mL serum were transferred to vials and stored at -20°C at the Akwesasne office. Periodically the samples were transferred to the University at Albany's Exposure Assessment Laboratory for analysis.

Measurement of PCBs

PCBs, p,p'-DDE (dichlorodiphenyldichloroethylene) and HCB (hexachlorobenzene) analyses were conducted at the University at Albany’s Exposure Assessment Laboratory. “[C]ongener-specific analysis was performed by parallel dual-column (splitless injection) gas chromatography with electron capture detection on an Agilent 6890 instrument” (Schell & Gallo, 2010, p. 248). For more information on the laboratory handling and analysis of the blood samples see DeCaprio (2005, 2000).

Eighty-three individual congeners of PCBs and 18 more PCB congeners as pairs or triplets were analyzed (Schell & Gallo, 2010; Schell et al., 2009). That is, a total of 101 individual congeners were analyzed. However, congeners for which all values were below the minimum detection level (MDL) were excluded. For those values below the MDL, the midpoint value between zero and the MDL was used. This is known as the MDL/2 substitution method. This was the measure used to calculate the total PCBs for each individual (Schell & Gallo, 2010; Schell et al., 2009; Schell et al., 2003).

Even though the dataset includes values for each specific PCB congener, analysis by individual PCB congeners was not performed because of the intercorrelation between the
congeners. Also, the large number of analyses involved would increase the likelihood of type I errors (Newman et al., 2006). Hence, the variable used as the independent variable in the present study was the sum of those PCB congeners detected in 50% of the participants and termed hereafter ΣPCB50%, thus reducing the number of substituted values employed. Congeners included in the ΣPCB50% measure were International Union for Pure and Applied Chemistry (IUPAC) congener numbers 28, 52, 74, 87, 95, 99, 101 [+90], 105, 110, 118, 138 [+163+164], 153, 180, and 187.

**Continuous Performance Test (CPT)**

The standard version of the Conners’ CPT II called the X-type CPT (version 3.1 for Windows) was employed in the present study to measure aspects of attention and impulsivity. The CPT II is a computerized measure of attention and impulsivity for ages 6 years and up and takes 14 minutes to complete (Conners, 2000). The CPT II test was administered in accordance with the guidelines provided in the Conners’ CPT II computer program version 3.0 user’s manual by a trained member of the Akwesasne research team. After obtaining informed assent and consent, the test instructions were read to the participants. Before taking the actual test, the participants were asked to take the standard practice test while being monitored by the administrator. The participant's name, gender and date of birth were entered into the program. The examiner instructed, “please remember to respond as fast as you can, but also as accurately as possible.” (Conners, p. 15).

The test was given on a Texas Instrument EXTENSA 560CD laptop with a 10.5 inch monitor in a quiet room in the participant’s house. The examiner remained in the room for both the standard practice test and the actual test. Participants were instructed to press the space bar for any letter except the target letter X.
The Conners’ standard version of CPT II consists of six blocks of trials with three sub-blocks and each sub-block includes 20 trials (letter presentations) for a total of 360 letter presentations. The letters (targets and non-targets) are shown for 250 ms with inter-stimulus intervals (ISIs) of 1, 2, and 4 seconds. The order of the ISIs varies within each block. That is, the ISI was 1, 2, or 4 seconds for the three sub-blocks within each block (Conners, 2000; Riccio et al., 2001).

The CPT II gives two measures of response accuracy - errors of omission and errors of commission. As stated previously, participants are required to press the space bar when any letter except the target letter X appears on the screen. Errors of omission are missed targets. That is, a response is not given (omitted) after a non-X letter appears on the screen. Errors of commission occur when a response is given (committed) to the letter X. Test takers should not respond when the letter X appears on the screen (Conners, 2000).

The normative clinical sample used in the development of the test included 378 individuals diagnosed with ADHD and 223 adults with “some type of neurological impairment” (Conners, 2000, p. 46). The non-clinical sample included 1920 individuals from the general population. Thirty sites from geographically diverse locations were used for the standardization process. The scores for a group of Asian and African American participants have been compared to the mean of the general population, a T-score of 50, in order to determine the applicability of CPT II norms to minority groups. The results show that the mean for the minority groups were 49.8 (Asians) and 50.6 (African Americans) for errors of omission and 49.1 (Asians) and 46.2 (African Americans) for errors of commission. The T-scores for the minority groups were very close to the mean of the general population (T-score of 50) (Conners).
The test manual reports that 520 cases were used for a split-half reliability procedure. The split-half reliabilities for Conners’ CPT were .94 for errors of omission and .83 for errors of commission. Twenty-three participants (10 non-clinical and 13 clinical) were used to assess test-retest reliability. The test-retest reliabilities over a 3-month period were generally high; for errors of omission it was .84 and for errors of commission it was .65 (Conners, 2000).

Validity is generally satisfactory. Discriminant and concurrent validity of the CPT has been examined. According to the test manual, CPT can discriminate between clinical and non-clinical groups (Conners, 2000). Furthermore, the test allows effectiveness of treatments and medications to be monitored. For example, in one study, children’s performance on the CPT improved after taking methylphenidate, a central nervous system stimulant (Aman et al., 1993). The test has also been validated as a sensitive assessment tool for ADHD in adults (Barkley et al., 1996).

The test manual (Conners, 2000) gives information to determine the validity of each protocol. For example, it is stated that a large number of omission errors (T-score > 100) is indicative of an invalid protocol which can happen if the test taker stops in the middle of the test or if the test taker has misunderstood the directions. In addition, a large number of perseveration responses (a response in less than 100 ms to a stimulus) can also indicate the invalidity of the protocol because it is impossible for one to process and respond to a stimulus this fast.

The program converts the omission error scores and the commission error scores to T-scores and percentiles which compare the respondent to the normative group of the same age group and gender. The age groups for the CPT II are as follows: 6-7, 8-9, 10-11, 12-13,
14-15, 16-17, 18-34, 35-54, and 55+. For skewed distributions, necessary transformations are carried out prior to calculating the T-scores. T-scores have a standard deviation of 10 and a T-score of 50 is the average for the comparison group. Therefore, a T-score of 60 is 1 standard deviation above average. Percentiles, on the other hand, give the percentage of the comparison group who scored below the participant’s score. For example, a commission percentile score of 30 shows that 30% of the comparison group made fewer commission errors. In short, high T-scores and percentile scores indicate a problem (Conners, 2000). The following table (Table 1) is given in the manual to help with the interpretation of omission and commission scores generated by CPT II (Conners, p. 23). T-scores will be the data used in the current analysis.

Table 1

*Interpreting CPT T-Scores and Percentiles*

<table>
<thead>
<tr>
<th>T-score</th>
<th>Percentile</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>65+</td>
<td>90+</td>
<td>Markedly atypical</td>
</tr>
<tr>
<td>60-64</td>
<td>85-89</td>
<td>Moderately atypical</td>
</tr>
<tr>
<td>55-59</td>
<td>70-84</td>
<td>Mildly atypical</td>
</tr>
<tr>
<td>45-54</td>
<td>31-69</td>
<td>Within the average range</td>
</tr>
<tr>
<td>40-44</td>
<td>15-30</td>
<td>Good performance</td>
</tr>
<tr>
<td>Under 40</td>
<td>Under 15</td>
<td>Very good performance</td>
</tr>
</tbody>
</table>

*Study Design*

*Hypotheses.* The purpose of the study was to examine the relationship between the participants' persistent PCBs body burdens and attention and impulsivity scores. The study
employed a correlational design testing two hypotheses derived from previous research (Darvill et al., 1996; Stewart, Reihman, Lonky, Darvill, & Pagano, 2004). The first hypothesis was that higher PCBs levels would be associated with higher omission errors (failing to respond to targets) which are indicative of inattention. The second hypothesis was that higher PCBs levels would be associated with higher commission errors which are indicative of impulsiveness.

*Control for other variables.* It is important to note that a correlational design does not allow determination of cause and effect relationships among the data. PCBs level, therefore, was investigated as a possible predictor of the outcome variable, but it is recognized that other variables might be influential. Unlike experimental studies with animals, in human studies one cannot control for possible confounding variables by random placement of the participants into treatment and control groups. Therefore, it is important to control for all major potential confounding variables statistically (Cicchetti, Kaufman, & Sparrow, 2004; Darvill et al., 1996; Jacobson & Jacobson, 2004).

Covariates are variables that influence the outcome measure in ways that may be misattributed to the independent variable. Choice of covariates to include in statistical analyses can be based on previous literature or theoretical considerations. However, most epidemiological studies of PCBs effects select covariates on empirical grounds and include all covariates that meet certain inclusion criteria for a given analysis. Commonly, all variables correlated at \( p < .20 \) with the outcome measure are included in the model. Thus, covariates are included on empirical grounds rather than theoretically (Stewart et al., 2004). This is an objective and a liberal inclusion method that allows even “marginalized variables” to be included (Stewart et al., p. 650) so that their role may be corrected for. Possible
covariates that were available in the data set are presented in Table 2. The socioeconomic index includes maternal education, maternal employment, marital status and various assets.
Table 2

*List of Possible Covariates*

<table>
<thead>
<tr>
<th>Toxicants</th>
<th>Maternal</th>
<th>Young adults</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCB (ppb)</td>
<td>WJ-R: BCAS</td>
<td>Gender</td>
</tr>
<tr>
<td>( p,p' )-DDE (ppb)</td>
<td>Breastfeeding duration (weeks)</td>
<td>Age (years)</td>
</tr>
<tr>
<td></td>
<td>Birth order</td>
<td>BMI (kg/m(^2))</td>
</tr>
<tr>
<td></td>
<td>Socioeconomic index</td>
<td>Cholesterol level (mg/dL)</td>
</tr>
<tr>
<td></td>
<td>Maternal smoking during pregnancy (#/day)</td>
<td>Total fat (g/day)</td>
</tr>
<tr>
<td></td>
<td>Number of social problems reported</td>
<td>Total protein (g/day)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ravens: RPM</td>
</tr>
<tr>
<td></td>
<td></td>
<td>TOMAL: CMIS</td>
</tr>
<tr>
<td></td>
<td></td>
<td>WJ-R: BCAE</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Computer in household (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Video games in household (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Summer school attendance during high school (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>School suspensions (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>School detentions (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Any arrests (y/n)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Current cigarette smoking (y/n)</td>
</tr>
</tbody>
</table>

Current alcohol consumption (y/n)

Abbreviations: ppb = parts per billion; WJ-R: BCAS = Woodcock Johnson-Revised Tests of Cognitive Ability Broad Cognitive Ability Standard; BMI= body mass index; Ravens: RPM = Ravens Progressive Matrices; TOMAL: CMIS = The Test of Memory and Learning: Composite Memory Index; WJ-R: BCAE = Woodcock Johnson-Revised Tests of Cognitive Ability: Broad Cognitive Ability Extended.
Data Screening

The dataset was screened for outliers, skewness, and multicollinearity. One participant was eliminated for having an invalid CPT protocol (test duration of 1 second). Another participant was eliminated for having an invalid CPT protocol (omission T-score of >100). The following variables were log transformed after examining each variable’s distribution, pp plots and histogram: PCBs, HCB, \( p,p'\)-DDE, total fat, total protein, cholesterol levels, and breastfeeding duration. The distribution of omission scores, although slightly skewed, did not warrant transformation. Multicollinearity diagnostics found no cause for concern about the variables in the regression model.

Data Analysis

The purpose of this study was to investigate the relationship between participant’s PCBs body burden and attention and impulsivity, testing two specific hypotheses. A study conducted by Bodnar, Prahme, Cutting, Denckla, and Mahone (2007) shows that the two dependent variables in the current study measure two different constructs. That is, their principal components analysis, using T-scores from the BRIEF (Behavior Regulation Inventory of Executive Function) scale and CPT-II variables, resulted in a three-factor solution where omission errors and commission errors loaded on different factors. In the present study, omission errors was significantly correlated with commission errors \( r = .28, p < .05 \). According to Cohen and Cohen (1983) guidelines, a correlation of this magnitude is considered small. Two simultaneous multiple regressions were performed investigating each dependent variable separately (Cohen & Cohen, 1983), as has been the practice in many publications in this field (e.g., Grandjean et al., 2001; Koopman-Esseboom et al., 1996; Nakajima et al., 2006; Rogan & Gladen, 1991; Schantz et al., 2001; e.g., Vreugdenhil, Slijper,
Mulder, & Weisglas-Kuperus, 2002; Winneke et al., 1998). A positive linear relationship was predicted between PCBs levels and both omission and commission scores.
Chapter 4

Results

Brief Overview

The study examined the relationship between PCBs body burden and attention and impulsivity as measures by the CPT in a group of young adults. It was hypothesized that higher PCB levels would be associated with inattention as measured by an increase in omission errors (failing to respond to targets). Furthermore, it was hypothesized that higher PCB levels would be associated with higher commission errors (responding to non-targets) which indicate impulsivity. SPSS17 was used for all analyses.

Descriptive Data for the Independent Variable

Descriptive statistics for the independent variable (ΣPCB50%) are presented in Table 3. The mean PCB level was .47 in the Akwesasne community whereas the median levels of total PCBs in the United States are between 2 to 7 ppb in whole serum (Kimbrough, 1995). However according to Schell and Gallo (2010), the Akwesasne youth “have levels of the sum of seven PCB congeners (IUPAC#s 118, 138, 153, 170, 180, 183, and 187) above the US 90th percentile (0.25 ppb)” (p.251) when compared to US youths ages 12-19.

Table 3

<table>
<thead>
<tr>
<th>Independent variable</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>ΣPCB50%</td>
<td>140</td>
<td>.47</td>
<td>.27</td>
<td>.20</td>
<td>2.50</td>
</tr>
</tbody>
</table>

Note. PCB values are measured in ppb.
Descriptive data for the Dependent Variable

Descriptive statistics for the dependent variables were analyzed and are presented in Table 4. In general, participants’ performances on the CPT fell within the average range on both omission and commission scores.

Table 4

Descriptive Data for Omission and Commission T-Scores

<table>
<thead>
<tr>
<th>Dependent variables</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Omission Scores</td>
<td>141</td>
<td>47.27</td>
<td>5.36</td>
<td>40.86</td>
<td>69.35</td>
</tr>
<tr>
<td>Commission Scores</td>
<td>141</td>
<td>53.47</td>
<td>9.94</td>
<td>32.64</td>
<td>79.89</td>
</tr>
</tbody>
</table>

*Note. T-score mean is 50 and SD is 10 in the normative sample.*

Covariates

Table 5 provides the frequency of the dichotomous covariates while descriptive data for the continuous covariates are presented in Table 6.

Table 5

Responses to Dichotomous Covariates

<table>
<thead>
<tr>
<th>Covariates</th>
<th>N</th>
<th>Yes</th>
<th>No</th>
</tr>
</thead>
<tbody>
<tr>
<td>Computer in household</td>
<td>140</td>
<td>104</td>
<td>36</td>
</tr>
<tr>
<td>Video games in household</td>
<td>140</td>
<td>102</td>
<td>38</td>
</tr>
<tr>
<td>Summer school attendance</td>
<td>139</td>
<td>46</td>
<td>93</td>
</tr>
<tr>
<td>Was suspended from school</td>
<td>140</td>
<td>38</td>
<td>102</td>
</tr>
<tr>
<td>Received detention in school</td>
<td>140</td>
<td>80</td>
<td>60</td>
</tr>
<tr>
<td>Any arrests</td>
<td>140</td>
<td>30</td>
<td>110</td>
</tr>
<tr>
<td>Currently consumes cigarettes</td>
<td>136</td>
<td>66</td>
<td>70</td>
</tr>
<tr>
<td>Currently consumes alcohol</td>
<td>140</td>
<td>110</td>
<td>30</td>
</tr>
</tbody>
</table>
### Table 6

**Descriptive Information on the Continuous Covariates**

<table>
<thead>
<tr>
<th>Covariates</th>
<th>N</th>
<th>Mean</th>
<th>SD</th>
<th>Minimum</th>
<th>Maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young adults</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>141</td>
<td>18.10</td>
<td>1.10</td>
<td>16.97</td>
<td>21.36</td>
</tr>
<tr>
<td>BMI (kg/m²)</td>
<td>136</td>
<td>25.87</td>
<td>4.94</td>
<td>18.01</td>
<td>45.84</td>
</tr>
<tr>
<td>Cholesterol level (mg/dL)</td>
<td>136</td>
<td>314.67</td>
<td>191.41</td>
<td>48.20</td>
<td>1276.10</td>
</tr>
<tr>
<td>Total fat (g/day)</td>
<td>136</td>
<td>88.20</td>
<td>43.68</td>
<td>18.90</td>
<td>300.70</td>
</tr>
<tr>
<td>Total protein (g/day)</td>
<td>136</td>
<td>76.48</td>
<td>35.94</td>
<td>19.30</td>
<td>271.80</td>
</tr>
<tr>
<td>Ravens: RPM</td>
<td>138</td>
<td>54.48</td>
<td>25.55</td>
<td>1.00</td>
<td>99.00</td>
</tr>
<tr>
<td>TOMAL: CMIS</td>
<td>138</td>
<td>101.15</td>
<td>9.70</td>
<td>69.00</td>
<td>123.00</td>
</tr>
<tr>
<td>WJ-R: BCAE</td>
<td>122</td>
<td>101.82</td>
<td>12.25</td>
<td>73.00</td>
<td>135.00</td>
</tr>
<tr>
<td><strong>Toxicants</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>HCB (ppb)</td>
<td>140</td>
<td>.04</td>
<td>.01</td>
<td>.01</td>
<td>.09</td>
</tr>
<tr>
<td>p,p'-DDE (ppb)</td>
<td>140</td>
<td>.38</td>
<td>.24</td>
<td>.00</td>
<td>1.61</td>
</tr>
<tr>
<td><strong>Maternal</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WJ-R: BCAS</td>
<td>128</td>
<td>95.56</td>
<td>10.65</td>
<td>72.00</td>
<td>125.00</td>
</tr>
<tr>
<td>Breastfeeding duration (weeks)</td>
<td>139</td>
<td>11.44</td>
<td>19.84</td>
<td>.00</td>
<td>120.00</td>
</tr>
<tr>
<td>Birth order</td>
<td>137</td>
<td>2.36</td>
<td>1.54</td>
<td>1.00</td>
<td>8.00</td>
</tr>
<tr>
<td>Socioeconomic index</td>
<td>141</td>
<td>24.05</td>
<td>6.19</td>
<td>1.00</td>
<td>37.00</td>
</tr>
<tr>
<td>Cigarette use during pregnancy (#/day)</td>
<td>140</td>
<td>3.45</td>
<td>6.84</td>
<td>.00</td>
<td>40.00</td>
</tr>
<tr>
<td>Number of social problems reported</td>
<td>140</td>
<td>.46</td>
<td>.81</td>
<td>.00</td>
<td>4.00</td>
</tr>
</tbody>
</table>

Abbreviations: ppb = parts per billion; WJ-R: BCAS = Woodcock Johnson-Revised Tests of Cognitive Ability Broad Cognitive Ability Standard; BMI = body mass index; Ravens: RPM = Ravens Progressive Matrices; TOMAL: CMIS = The Test of Memory and Learning: Composite Memory Index; WJ-R: BCAE = Woodcock Johnson-Revised Tests of Cognitive Ability: Broad Cognitive Ability Extended.
Bivariate correlations were conducted in order to select the variables to be included in the model as covariates. Results of the correlations are presented in Table 7. Sex, video games in household, \( p,p' \)-DDE (ppb), maternal smoking during pregnancy, and number of social problems reported were correlated at \( p < .20 \) with errors of omission and were thus included in the final analysis for that measure. For errors of commission, age, computer and video games in household, and current alcohol consumption were correlated at \( p < .20 \) and were included in the final analysis for commission errors.
Table 7

Correlation of Covariates with Attention Variables

<table>
<thead>
<tr>
<th>Possible covariate</th>
<th>Errors of omission</th>
<th>Errors of commission</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Young adult measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Age (years)</td>
<td>.03</td>
<td>.19*</td>
</tr>
<tr>
<td>Sex (M/F)</td>
<td>.16*</td>
<td>.07</td>
</tr>
<tr>
<td>BMI (kg/m$^2$)</td>
<td>.09</td>
<td>-.02</td>
</tr>
<tr>
<td>Cholesterol level (mg/dL) $^a$</td>
<td>.03</td>
<td>.07</td>
</tr>
<tr>
<td>Total fat $^a$</td>
<td>.03</td>
<td>.08</td>
</tr>
<tr>
<td>Total protein $^a$</td>
<td>-.02</td>
<td>.08</td>
</tr>
<tr>
<td>Ravens: RPM</td>
<td>.01</td>
<td>-.01</td>
</tr>
<tr>
<td>TOMAL: CMIS</td>
<td>.04</td>
<td>.05</td>
</tr>
<tr>
<td>WJ-R: BCAE</td>
<td>-.01</td>
<td>.02</td>
</tr>
<tr>
<td>Computer in household</td>
<td>-.02</td>
<td>-.20*</td>
</tr>
<tr>
<td>Video games in household</td>
<td>-.12*</td>
<td>-.14*</td>
</tr>
<tr>
<td>Summer school attendance</td>
<td>.03</td>
<td>.09</td>
</tr>
<tr>
<td>School suspensions</td>
<td>-.06</td>
<td>-.05</td>
</tr>
<tr>
<td>School detentions</td>
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<td>.02</td>
</tr>
<tr>
<td>Any arrests</td>
<td>.02</td>
<td>.07</td>
</tr>
<tr>
<td>Current cigarette consumption</td>
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<td>.10</td>
</tr>
<tr>
<td>Current alcohol consumption</td>
<td>-.00</td>
<td>.13*</td>
</tr>
<tr>
<td><strong>Toxicants</strong></td>
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<td></td>
</tr>
<tr>
<td>HCB (ppb) $^a$</td>
<td>.04</td>
<td>.02</td>
</tr>
<tr>
<td>$p,p'$-DDE (ppb) $^a$</td>
<td>.12*</td>
<td>.04</td>
</tr>
<tr>
<td><strong>Maternal measures</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>WJ-R: BCAS</td>
<td>.04</td>
<td>.06</td>
</tr>
<tr>
<td>Breastfeeding duration $^a$</td>
<td>.02</td>
<td>-.04</td>
</tr>
<tr>
<td>Birth order</td>
<td>.04</td>
<td>-.03</td>
</tr>
<tr>
<td>Socioeconomic index</td>
<td>.07</td>
<td>-.07</td>
</tr>
<tr>
<td>Maternal smoking during pregnancy</td>
<td>.20*</td>
<td>.05</td>
</tr>
<tr>
<td>Number of social problems reported</td>
<td>.16*</td>
<td>.10</td>
</tr>
</tbody>
</table>

Hypothesis 1: Association between PCBs Levels and Errors of Omission

A simultaneous multiple regression was performed to examine the relationship between ΣPCB50% and errors of omission controlling for all covariates that had correlated with omission errors at $p < .20$. The variables of sex, video games in household, $p,p'$-DDE (ppb), maternal smoking during pregnancy, and number of social problems reported were included in the model as covariates. A logarithmic transformation was used for $\Sigma$PCB50% and $p,p'$-DDE (ppb) to reduce skewness and improve normality. The predictors within the model accounted for 10% of the variance in errors of omission ($R^2 = .10$), which was statistically significant $F(6, 131) = 2.33, p = .04$. Maternal smoking during pregnancy was the only significant unique predictor of inattentiveness within the model ($\beta = .20, p = .03$). A positive but nonsignificant relationship was found between PCBs levels and errors of omission. Hence hypothesis 1 was not supported. Results of the analysis are given in Table 8.
Table 8

*Regression Analysis for Omission Errors and $\Sigma$PCB50% ($N = 138$)*

<table>
<thead>
<tr>
<th>Variables</th>
<th>$B$</th>
<th>SE $B$</th>
<th>$B$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sex</td>
<td>1.57</td>
<td>.88</td>
<td>.15</td>
</tr>
<tr>
<td>Video games in household</td>
<td>-.58</td>
<td>.96</td>
<td>-.05</td>
</tr>
<tr>
<td>$p,p'$-DDE $^a$</td>
<td>1.02</td>
<td>.69</td>
<td>.14</td>
</tr>
<tr>
<td>Maternal smoking during pregnancy</td>
<td>.15*</td>
<td>.07*</td>
<td>.20*</td>
</tr>
<tr>
<td>Number of social problems</td>
<td>.62</td>
<td>.55</td>
<td>.10</td>
</tr>
<tr>
<td>$\Sigma$PCB50% $^a$</td>
<td>.19</td>
<td>1.18</td>
<td>.02</td>
</tr>
<tr>
<td>$R^2$</td>
<td></td>
<td></td>
<td>.10</td>
</tr>
<tr>
<td>Adjusted $R^2$</td>
<td></td>
<td></td>
<td>.06</td>
</tr>
</tbody>
</table>

$^a$ Log transformed.
* $p < .05.$

*Hypothesis 2: Association between PCB Levels and Errors of Commission*

A simultaneous multiple regression was performed to examine the relationship between $\Sigma$PCB50% and errors of commission controlling for all covariates that had correlated with commission errors at $p < .20$. The variables of age, computer and video games in household, and current alcohol consumption were included in the model as covariates. $\Sigma$PCB50% was log transformed to reduce skewness and improve normality. The predictors within the model accounted for 9% of the variance in errors of omission ($R^2 = .09$), which was statistically significant $F(5, 133) = 2.56, p = .03$. A positive but nonsignificant relationship was found between PCBs levels and errors of commission. Hence hypothesis 2 was not supported. Results of the analysis are given in Table 9.
### Table 9

**Regression Analysis for Commission Errors and ΣPCB50% (N = 139)**

<table>
<thead>
<tr>
<th>Variables</th>
<th>B</th>
<th>SE B</th>
<th>β</th>
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</thead>
<tbody>
<tr>
<td>Age</td>
<td>.98</td>
<td>.83</td>
<td>.11</td>
</tr>
<tr>
<td>Computer in household</td>
<td>-3.80</td>
<td>2.02</td>
<td>-.17</td>
</tr>
<tr>
<td>Video games in household</td>
<td>-3.15</td>
<td>1.88</td>
<td>-.14</td>
</tr>
<tr>
<td>Current alcohol consumption</td>
<td>1.33</td>
<td>2.21</td>
<td>.06</td>
</tr>
<tr>
<td>ΣPCB50% (^a)</td>
<td>1.58</td>
<td>2.15</td>
<td>.06</td>
</tr>
</tbody>
</table>

\[ R^2 \]

\[ \text{Adjusted} \ R^2 \]

\[ .09 \]

\[ .05 \]

\(^a\) Log transformed.

\(^*\) \( p < .05 \).
Chapter 5
Discussion

Brief Overview

The long-term developmental and neurobehavioral effects of low levels of PCB exposure have substantial societal importance. However, to date only a few studies have investigated the effects in adults (Haase et al., 2009; Schantz et al., 2001). The present study adds to the large body of PCB literature by investigating the effects of PCB exposure on attention and impulsivity as measured by the CPT’s omission and commission errors in a group of 17-21 year olds.

There are both theoretical and empirical reasons to expect that exposure to PCBs might affect the ability to maintain attention and increase impulsivity. PCBs have been found to influence the endocrine system by changing dopamine (Seegal et al., 1994, 2005, 2010) and thyroid levels (Brouwer et al., 1998; Goldey et al., 1995a; Koopman-Esseboom et al., 1994; Morse et al., 1993; Osius et al., 1999; Schell et al., 2004) in both animals and humans. PCB related changes in thyroid were found by Schell et al. with the MAWBS adolescent participants.

These changes in turn can result in cognitive and behavioral disturbances (Jones & Miller, 2008) and as such may affect arousal, activity level, attention, and impulsivity. In fact, low levels of dopamine have been associated with ADHD (Sullivan & Brake, 2003; Van der Kooij & Glennon, 2007). Moreover, animals exposed to PCBs exhibit some of the characteristics found in children with ADHD (Rice, 2000). It is important to investigate the relationship between PCBs and attention and impulsivity because because children who
suffer from ADHD-like symptoms are more likely to have problems with school achievement (Barkley et al., 1990; Fischer et al., 1990).

PCB exposure has produced an array of executive functioning deficits (Jacobson & Jacobson, 1996, 2003; Stewart et al., 2003a, 2005, 2006; Vreugdenhil et al., 2004a). Although a great deal of research, including previous studies of Akwesasne adolescents (Newman et al., 2006, 2009), has focused on sensory/motor, cognitive, and memory functioning (Chen et al., 1992; Daniels et al., 2003; Darvill et al., 2000; Grandjean et al., 2001; Jacobson & Jacobson, 1996; Jacobson et al., 1984b; Jacobson et al., 1990b; Jacobson et al., 1985; Lai et al., 1994; Lonky et al., 1996; Nakajima et al., 2006; Newman et al., 2006, 2009; Patandin et al., 1999; Rogan et al., 1986; Stewart et al., 2003b; Vreugdenhil et al., 2002; Winneke et al., 1998) fewer studies have investigated effects on behaviour and attention (Chen et al., 1994; Chen & Hsu, 1994; Grandjean et al., 2001; Jacobson & Jacobson, 2003; Jacobson et al., 1990a, 1992; Lai et al., 2002; Sajiv et al., 2008, 2010; Stewart et al., 2003a, 2005; Verner et al., 2010; Vreugdenhil et al., 2004a, 2004b).

Furthermore, only a few epidemiological studies have investigated attention and impulsivity using different forms of the CPT (Grandjean et al., 2001; Jacobson & Jacobson, 2003; Jacobson et al., 1992; Stewart et al., 2003a, 2005; Vreugdenhil et al., 2004a). Negative effects have been found in Oswego (Stewart et al., 2003a, 2005), Michigan (Jacobson & Jacobson), Netherlands (Vreugdenhil et al., 2004a), and the Faroe Islands (Grandjean et al.) in young children.

The present study was the first to investigate the effects of PCBs on attention and impulsivity using X-CPT with a group of young adults. It is important to investigate different age groups because different effects of the same outcome have been observed in different age
groups in past PCBs studies (Boucher et al., 2009). For example, the Oswego cohort used the McCarthy Scales of Children’s Abilities (MSCA) at 3 and 4.5 years of age (Stewart et al., 2003b). Negative effects were found only in 3 year olds. In Faroe Islands on the other hand, no relationship was found between cord PCB levels and WISC-R at age 7 (Grandjean et al., 2001) whereas in Michigan prenatal PCB exposure was related to WISC-R at age 11 (Jacobson & Jacobson, 1996). This may be the case because some areas of the brain such as the frontal cortex continue to grow through late adolescence (Segalowitz & Davies, 2004) and so may be vulnerable at different developmental periods.

Findings of the Current Study

The results of the current study do not support the two hypotheses of the study. PCBs were not linked to increased errors of omission nor commission in a computerized task measuring aspects of attention and impulsivity. Despite the findings of some previous studies, the current results confirm those of an earlier investigation (Aucompaugh, 2005) with the same participants using behavior ratings of attention. In this earlier study done when the participants were adolescents, blood PCB levels were not related to ratings of attention completed by parents and teachers. In the Aucompaugh study, no effects were found with the inattentive-passive subscale of the Conners’ Rating Scale for Teachers (CRS-T) or the inattentiveness subscale of the Attention Deficit Disorder Evaluation Scale (ADDES) Home and School versions. The findings drawn from the current study of young adults are also similar to the results of Jacobson and Jacobson’s (1992) study where no relationship was found between prenatal PCB exposure and attention in 4 year olds.

By contrast, the effects are inconsistent with those of past studies linking prenatal PCB exposure to an increase in errors of commission (Jacobson & Jacobson, 2003; Stewart
et al., 2003a, 2005). However, one must keep in mind that it is difficult to compare the results of the current study to past CPT studies because of the differences in the type of CPT employed, the timing of exposure (prenatal vs. postnatal), the choice of PCB congeners used, and the age of the participants.

It is important to note that epidemiological PCB studies are designed to extend and duplicate past studies. The results of studies become credible when the findings in one study duplicate another investigating the same endpoints (Stewart et al., 2004). In fact the strength of conclusions drawn by researchers in the field depends mainly on an array of studies investigating the same end point. The more similar the findings between the studies the more confident we can be of the results.

The current study supports the findings of Aucompaugh (2005) gained from the same population by replicating her results and by addressing some of the limitations of her study. For example, the current study used a computerized vigilance test in order to obtain an objective measure of the outcome variables instead of using rating scales. Furthermore, there was not much variability in the ratings completed by parents and teachers in the Aucompaugh study. The use of the CPT increased the variability in the two measured endpoints (See Appendices B and C). Lastly, the fact that similar results are provided by two studies using the same population but at different age periods, with different measures of attention, increases credibility by validating each other. That is, together they show that PCBs exposure was not related to these domains given the current body burdens measured in the current sample.

Though it was not a particular focus of the present study, maternal smoking during pregnancy, unlike PCBs level, was found to be related to omission scores. This is not
surprising because maternal smoking during pregnancy has been linked to inattentiveness in other studies (Streissguth et al., 1984) and in the MAWBS study (Aucompaugh, 2005). However in interpreting this finding one must keep in mind that this variable was a self-report by the mothers many years after their pregnancy. Therefore, the variables are estimates and caution is warranted not to overgeneralize this finding. Also the design of the study does not allow us to infer a direct causal relationship between maternal smoking and CPT performance.

**Explanation of Findings**

In this young adult sample, current PCB levels were not related to current measures of attention and impulsivity. These findings support those of Aucompaugh (2005) with mostly the same sample where no relationship was found between blood PCB levels and behavior ratings of attention. These findings are discrepant from some other published findings (Jacobson & Jacobson, 2003; Stewart et al., 2003a, 2005) although supported by others (Jacobson et al., 1992). One possible explanation for the findings of this study could be the low levels of serum PCB levels. In the Akwesasne community, the mean of $\Sigma$PCB50% was .47 ppb whereas the median levels of total PCB in the United States are between 2 to 7 ppb in whole serum (Kimbrough, 1995). A possible reason for the low levels of PCBs in the young adult’s blood can be the fact that they had been raised after advisories went into place resulting in a decrease of local fish and food consumption by the young adults themselves (Hoover, 2010). Perhaps if PCB exposure levels (from fish eating and other sources) had been greater, effects on attention may have been evident, but this cannot be determined from the current data.
Furthermore, past studies have used different congeners of PCBs to compute PCB exposure levels. For example, the Michigan study used Aroclors 1016 and 1260 (Jacobson & Jacobson, 2003) whereas the Oswego study used persistent PCB congeners (IUPAC congener numbers: 170+190, 172, 174, 177, 179, 180, 183, 185, 187+181, 194, 195, 199, 203+196, 206) (Stewart et al., 2003a; Stewart et al., 2005). In the current study, 101 individual congeners were analyzed. Congeners included in the current analysis were a sum of those found in at least 50 percent of the population: IUPAC congener numbers 28, 52, 74, 87, 95, 99, 101[+90], 105, 110, 118, 138 [+163+164], 153, 180, 187. It is important to note that PCB concentrations are higher in earlier studies in the US than those conducted later (Longnecker et al., 2003). As a result, it is difficult to compare findings among the various studies.

The timing of exposure could have also played a role here. Overall, prenatal PCB exposure has been associated with more negative outcomes than postnatal exposure (Darvill et al., 2000; Fein et al., 1984; Jacobson & Jacobson, 1996, 2003; Jacobson et al., 1992; Lai et al., 1994, 2002; Stewart et al., 2003a) though postnatal affects have been observed (Jacobson et al., 1990a). CPT studies that have found an effect have all used prenatal exposure levels (Jacobson & Jacobson, 2003; Stewart et al., 2003a, 2005). One explanation can be that prenatal exposure continues through a critical period in development (Jacobson et al., 1984a).

Also, the current study is the first to use young adults whereas past studies that have found a relationship have all used young children. The impact of PCBs is likely to vary according to a person’s age because of such factors as continued brain development at least through late adolescence (Segalowitz & Davies, 2004), ongoing metabolism of PCBs, and longitudinal changes in the PCBs themselves.
It is important to note that some of the studies that have found a relationship between exposure and attention and impulsivity have used different outcome measures. In Taiwan, parents completed the Rutter Child Behavior Scale A which focuses on behavioral problems and the Werry-Weiss-Peters scale (Chen et al., 1994) which focuses on activity. Both scales are subjective. Furthermore, the study used one scale (the Rutter Child Behavior Scale A) that was validated in Britain but not in Taiwan. In a follow up study, parents completed the Achenbach Child Behavior Checklist (CBCL) which measures emotional and behavioral problems and the Rutter Child Behavior Scale A (Lai et al., 2002). Only one study in Taiwan used an objective auditory vigilance test (Chen & Hsu, 1994). It should be noted that the Taiwanese children were exposed to large quantities of PCBs. In a study conducted in Massachusetts, the researchers used the Conner’s Rating Scale for Teachers in which umbilical cord PCB levels were associated only with Conners’ ADHD index but not with the inattentive, hyperactive-impulsive, and total subscales of the measure (Sajiv et al., 2010). Similarly, in Aucompaugh (2005), no relationship was found between blood PCB levels of the MAWBs sample and the inattentive-passive subscale of the Conners measure and the inattentiveness subscale of the Attention Deficit Disorder Evaluation Scale (ADDES) Home and School versions.

Strengths of the Study

The current study has several methodological strengths. In nonexperimental design, when one cannot control for confounding variables by placement of subjects into control and experimental groups, it is important to control for these factors statistically (Cicchetti et al., 2004; Darvill et al., 1996; Jacobson & Jacobson, 2004). Great care was taken to control for other factors that could have influenced the outcome measure in the current study. To
accomplish this, a large array of covariates were correlated with the outcome measures and those correlated with the outcome measures at $p < .20$ were included in the model (Stewart et al., 2004). The current study controlled for variables deriving from both genetic (i.e. maternal cognitive level) and environmental sources (e.g. SES) in this manner. In fact, according to Cicchetti et al. (2004), it is important to control for parents’ IQ when studying attention to control for the cognitive contribution to CPT performance. The study also included prenatal factors such as maternal smoking during pregnancy. Furthermore, the study controlled for other neurotoxicants such as HCB and $p,p'$-DDE.

A second strength of the current study was the choice of the outcome variable used. The X-CPT is a valid and reliable measure for the outcome variables of interest. It is an objective test and allows the researcher to assess the participant’s actual behavior by requiring the individual to respond to infrequent targets at random interval and by refraining from responding to non-targets (Conners, 2000; Riccio et al., 2001). Therefore, unlike rating scales, the measure is not susceptible to rater bias. Errors of omission reflect attentional problems and commission errors reflect impulsivity (lack of response inhibition) (Conners).

The CPT has been found to be "sensitive" (Boucher et al., 2009, p.14) in past PCBs studies. That is, the test has been able to detect subtle negative PCB effects in Michigan and Oswego (Jacobson & Jacobson, 2003; Stewart et al., 2003a, 2005). It is also capable of investigating prenatal substance exposure (Leech et al., 1999; Noland et al., 2005; Streissguth et al., 1986; Streissguth et al., 1984) and neurobehavioral effects of occupational exposure to neurotoxic chemicals (Estrin et al., 1987; Tsai & Chen, 1996).

Another important consideration is the suitability of a test for a given population, and the adherence to standardized procedures of administration. The X-CPT is suitable for use
with minority groups and the given age group (Conners, 2000). Trained examiners were used. Data collectors were trained and supervised by the primary investigators for the project at the University at Albany following the guidelines provided by the manual. Furthermore, there were only two invalid protocols which indicate that the participants did not have difficulty following directions and completing the task.

Literature review and theory were used to select the two end points to be studied, and hypotheses were stated in advance (Darvill et al., 1996; Stewart et al., 2004). Steps were taken to limit the number of comparisons made in each regression by including only those covariates that correlated with the outcome measure at $p < .2$. Although multiple comparisons were made, which can increase the likelihood of making a Type I error (claiming a relationship exists when it does not), this approach is consistent with many epidemiological PCBs studies. Despite criticism (Cicchetti et al., 2004) for using multiple comparisons without the use of the Bonferroni adjustments to reduce Type I error, many researchers in the field argue against using the adjustment (Poole, 1991; Rothman, 1990) because it increases the risk of a Type II error (claiming a relationship does not exist when in fact it does) (Schantz et al., 2004). Yet others point out that because PCB effects are small, the Bonferroni adjustment will make it very difficult to show negative exposure effects (Jacobson & Jacobson, 2004). According to Schantz et al. (2002), when one is dealing with “important public health issues, [making a] Type II error is a serious concern and should not be ignored” (p. A 71). Furthermore, the two outcome measures used in the present study were not highly correlated. As a result we can be confident that the outcome variables were not measuring the same underlying construct.
PCB levels were obtained using the latest technology available at the time of testing. This allowed for congener specific analysis of PCBs and a total of 101 individual congeners were analyzed (Schell & Gallo, 2010; Schell et al., 2009). The sum of those PCBs found in at least 50% of the participants was the measure used in the present study. As a result, the study used the actual PCB levels in the young adults’ blood at the time of the measurement of the outcome measures, rather than PCB measures taken years before during maternal pregnancy or during lactation. Although measures of prenatal exposure were not used, the participants had been selected to include those born to mothers who were likely to have consumed fish before advisories went into place. As young adults, the participants were likely to have been exposed to ongoing sources of PCBs in their diet and through the environment, as well as pre and perinatally.

Limitations and Suggestions for Future Studies

There are some limitations that must be considered. These suggest directions for future research.

First, despite the advantage of having available measures of current PCB body burden, prenatal PCB exposure has been associated with more negative outcomes (Darvill et al., 2000; Fein et al., 1984; Jacobson & Jacobson, 1996, 2003; Jacobson et al., 1992; Lai et al., 1994; Lai et al., 2002; Stewart et al., 2003a), specifically in CPT studies (Jacobson & Jacobson, 2003; Stewart et al., 2003a, 2005). Therefore, it is important for future studies to also obtain prenatal PCB exposure levels to investigate effects on the development of sustained attention.

Another limitation of the study is that some of the information collected (e.g. breastfeeding history, diet and during pregnancy cigarette smoking) was gained by maternal
recall and could be biased or inaccurate. Measures recorded during pregnancy would increase accuracy.

In studies of this kind there are many variables having potential impact on children's behavior, functioning and development. Many such variables were measured in the present study, but there are others that could be considered in future studies. Among these are characteristics of the parents that could contribute to the child's outcome scores (such as parental attention and impulsivity, parent ADHD), maternal diet and ingestion of substances such as caffeinated drinks, legal and illegal drugs during pregnancy, or measures of other toxicants such as methylmercury or lead.

Many cognitive and academic tasks require attention. In fact, past studies show a negative relationship between attention problems and academic achievement (Gordon et al., 1994; Kellam et al.; Rowe & Rowe, 1992). Although the results of this study showed that blood PCB levels were not related to attention and impulsivity, it is still important to investigate PCBs role in other educational outcomes. For example, future studies could use information about school achievement, such as that available on report cards and from standardized testing in schools, to investigate the relationship between PCB exposure and academic achievement. Moreover, the relationship should also be investigated with other age groups, and also with individuals exposed to higher levels of PCBs.

Summary and Implications

Although PCB bans have been in place in many industrialized nations since the late 1970s, communities are still at risk today because of the persistent nature of the chemical, the improper disposal of the chemical mainly by industries, and contaminated food. Therefore, it remains important to study the long-term effects of PCBs in the general population.
Two multiple regressions were performed to investigate the relationship between PCBs and attention and impulsivity in a group of Akwesasne young adults exposed to PCBs. A wide range of possible confounding variables was examined. No adverse relationship was found between exposure level and attention and impulsivity as measured by omission and commission scores of the CPT. However, an unexpected finding was that maternal smoking during pregnancy was associated with increased omission scores, which is indicative of a decreased attentional performance in the young adults.

The Akwesasne community is concerned about the impact of environmental pollution on the environment and its people especially the young. Their concern is not without merit because their PCB levels have been related to some negative health and cognitive outcomes (Newman et al., 2006, 2009; Schell et al., 2004, 2009). However the current study confirms an earlier one (Aucompaugh, 2005) that there is no relationship between PCB levels and attention and impulsivity in Akwesasne adolescents or young adults.
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Porterfield, S. P. (1994). Vulnerability of the developing brain to thyroid abnormalities: Environmental insults to the thyroid system. Environmental Health Perspectives, 102, 125-130.


### Appendix A

**Summary of Akwesasne Studies of PCBs and Human Cognition and Behavior**

<table>
<thead>
<tr>
<th>Study</th>
<th>Exposure Measure</th>
<th>Outcome Measure</th>
<th>Findings</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Newman et al., 2006)</td>
<td>ΣPCB50%</td>
<td>Woodcock Johnson-Revised</td>
<td>↓ in Long Term Retrieval &amp; Comprehension-Knowledge of the WJ-R</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Test of Memory and Learning</td>
<td>↓ in TOMAL’s Delayed Recall</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ravens Progressive Matrices</td>
<td></td>
</tr>
<tr>
<td>(Newman et al., 2009)</td>
<td>Σdioxin-like PCB50%</td>
<td>Woodcock Johnson-Revised</td>
<td>↓ in Ravens, TOMAL’s Delayed Recall, and WJ-R’s Long Term Retrieval scores with Dioxin-like PCBs</td>
</tr>
<tr>
<td></td>
<td>Σnon-dioxin-like PCB50%</td>
<td>Test of Memory and Learning</td>
<td>↓ in TOMAL’s Delayed Recall and WJ-R’s Long Term Retrieval scores with non-dioxin-like PCBs</td>
</tr>
<tr>
<td></td>
<td>Σpersistent PCB50%</td>
<td>Ravens Progressive Matrices</td>
<td>↓ in TOMAL’s Delayed Recall, WJ-R’s Long Term Retrieval, and WJ-R’s Auditory Processing with persistent PCBs</td>
</tr>
<tr>
<td></td>
<td>Σlow-Persistent PCB50%</td>
<td>Ravens Progressive Matrices</td>
<td>↓ TOMAL’s Delayed Recall, WJ-R’s Long Term Retrieval, and WJ-R’s Comprehension with low-persistent PCBs</td>
</tr>
<tr>
<td>(Aucompaugh, 2005)</td>
<td>ΣPCB50%</td>
<td>Conners’ Rating Scale for Teachers (CRS-T)</td>
<td>Not related to the inattentive-passive subscale of CRS-T</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Attention Deficit Disorder Evaluation Scale (ADDES) Home and School versions</td>
<td>Not related to the inattentiveness subscale of the Attention Deficit Disorder Evaluation Scale (ADDES) Home and School versions</td>
</tr>
</tbody>
</table>
Appendix B

Histogram for Errors of Omission

Mean = 47.27
Std. Dev. = 5.358
N = 141
Appendix C

Histogram for Errors of Commission

Mean = 53.47
Std. Dev. = 9.943
N = 141