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THE CONTINUOUS PERFORMANCE TEST: SEPARATE AND INTERACTIVE EFFECTS OF TASK AND SUBJECT VARIABLES ON CHILDREN'S VIGILANCE

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ABSTRACT

The interplay among task and subject variables in the context of children's vigilance was scrutinized in the present study to facilitate derivation of hypotheses concerning the mechanisms and processes responsible for individual differences in children's vigilance. Two distinct (AX and BX-double letter model) continuous performance tests (CPT) were administered under two levels of target density (low, high) to 352 children ranging from 6 to 15 years of age recruited from community elementary schools. A three-tier data analytic approach revealed that (a) CPT omission (OE) and commission (CE) errors represent psychometrically distinct constructs and must be examined separately; and (b) task (CPT model, target density) and subject (particularly age and IQ) variables significantly influence children's vigilance performance but show different patterns of interaction for omission and commission errors. Relationships associated with omission errors were generally more complex than those involving commission errors, nearly always involved model effects, and suggest that controlled processing characteristics associated with the BX model place greater demands on sustained attention and result in more rapid vigilance decay in children. The interaction among model, target density, and time proved contrary to expectations based on the signal probability hypothesis. Possible explanations of these findings and implications for research and clinical practice are discussed.

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CHAPTER 1. INTRODUCTION

The Continuous Performance Test (CPT) is a popular laboratory instrument used to measure vigilance or maintenance of attention for infrequent but critical events over prolonged intervals of time. Its prevalent use by clinical researchers is largely due to four factors. Some, and particularly recent versions of the CPT have acceptable psychometric properties (Conners, 1995; Greenberg & Waldman, 1993; Seidel & Joschko, 1991). Administration of the task is neither time consuming nor cumbersome. Its sensitivity in discerning select drug (e.g., psychostimulants, tricyclics, antipsychotics) from non-drug effects is well established (Conners, 1995; Klorman et al., 1988; Matier, Halperin, Sharma, Newcorn, & Sathaye, 1992; Losier, McGrath, & Klein, 1996; Rapport & Kelly, 1991). And, the instrument has promising potential for detecting attentional difficulties and differences within and across various clinical populations (Barkley, Grodzinsky, & DuPaul, 1992; Halperin et al., 1990; Rapport, Chung, Shore, Denney, & Isaacs, 2000). More recently, measures derived from the CPT have served as integral components of complex models of attention (Mirsky, Anthony, Duncan, Ahearn, & Kellam, 1991) and information processing (Sergeant & van der Meere, 1990).

Historical Review

Early Clinical Applications

CPT paradigms were initially used to study vigilance in children during the early 1970s. The first published study (Sykes, Douglas, Weiss, & Minde, 1971) compared the performance of hyperactive and matched normal control children on three different CPT paradigms ("X", "AX", and geometric shape versions). Hyperactive children detected fewer correct target stimuli (i.e., lower hit rate) than control children in this and a subsequent study

(Sykes, Douglas, & Morgenstern, 1973), whereas higher commission errors were reported only in the latter investigation. Following a 7-year lull, 20 comparison studies were published during the 1980s. The resurging interest corresponded with the change in diagnostic nomenclature from Hyperkinetic Reaction of Childhood to Attention Deficit Disorder with Hyperactivity (American Psychiatric Association, 1980), and reflected increased recognition that attentional difficulties were prominent and nearly always present in hyperkinetic children. Interest in assessing and understanding attentional difficulties between children with ADHD and relevant control groups continued through the last decade as evidenced by the 27 comparison studies published between 1990 and 1999 (for a review, see Chung, Denney, & Rapport, 1999).

Comparison Studies

Despite the developing literature pertaining to vigilance differences within and across normal and clinical child populations, its collective findings are replete with contradictions and failed replications. There are several possible explanations for this state of affairs. Methodological and diagnostic criteria differences among studies notwithstanding, there has been an inconsistent application of appropriate controls for the numerous task and subject variables whose influences on vigilance performance have been clearly demonstrated (Corkum & Siegel, 1993; Seidel & Joschko, 1990; 1991). For example, a medley of operationally different CPT paradigms are described in the literature (e.g., X-only, AX, BX or double letter) and routinely compared to one another without regard for differences in basic task parameters among studies (e.g., type of paradigm, intertrial stimulus interval, target frequency). This has occurred despite an extensive literature suggesting that such variations in task parameters may affect the mode of information processing required for successful performance (Koelega, Brinkman, Hendrik, & Verbaten, 1989; Scharchar, Logan, Wachsmuth, & Chajczdy, 1988; Sergeant & van der Meere, 1990).

Task Variables

CPT paradigms

Extant research examining children's performance on different CPT paradigms is limited but informative. Performance differences between children with ADHD and normal controls using an X-only (respond whenever the letter "X" is shown) and AX (respond whenever the letter "X" is immediately preceded by the letter "A") paradigm while holding target density (frequency of targets relative to non-targets) constant were examined in four studies (Michael, Klorman, Salzman, Borgstedt, & Dainer, 1981; Schachar et al., 1988; Seidel & Joschko, 1990; Sykes et al., 1971). Consistent differences in performance were found in all four investigations, wherein children (both ADHD and normal controls) responded more quickly (i.e., faster reaction time) and emitted fewer errors (omission, commission) under the X-only paradigm. Performance differences using an X-only and BX (respond whenever predetermined consecutive numerals such as 1, 9 are shown) paradigm were examined in 16 children with ADHD and matched controls (Strandburg et al., 1996). Both tasks were of equal duration (11-min), equated for target ratio (1:5 targets per stimuli), and used preprogrammed distracter digits on every trial to enhance difficulty and minimize ceiling effects. Results revealed significantly more errors (both omission and commission) and slower reaction times for the BX paradigm in both groups of children. Collectively, these results provide convincing evidence that a subtle change in task demands, such as requiring the identification of a single stimulus letter versus a letter or digit combination, can significantly alter vigilance performance in children.

Other Task Variables

Comparatively less information is available concerning the effects of other task variables on vigilance performance in children. Two studies manipulating the intertrial stimulus interval (ISI: time interval between the appearance of one stimulus and an ensuing stimulus) generated inconsistent results, with one showing longer intervals associated with an increase in errors and decrease in hits (Chee, Logan, Schachar, Lindsay, & Wachsmuth, 1989), and the other showing an opposite pattern of results (Sykes et al., 1971). Stimulus display time has been infrequently investigated with briefer displays associated with greater errors (Chee et al., 1989). The effect of target density (ratio of target to non-target stimuli) on children's vigilance is unknown. In adults, it appears to exert robust effects on vigilance performance by increasing signal probability (under high target density conditions), with resulting improvement in detection efficiency and attenuated vigilance decay (Jenkins, 1958; See, Howe, Warm, & Dember, 1995; Warm & Alluisi, 1971).

Finally, the manner in which target density and paradigm (AX, BX) interact in affecting children's vigilance performance is currently unknown, but might be hypothesized to exert differential effects on omission and commission errors. For example, maintenance of attention (omission errors) may be particularly affected by paradigm difficulty owing to evaluative processes, whereas impulsivity (commission errors) may be influenced to a greater extent by differences in target frequency (See et al., 1995).

Subject Variables

Subject variables such as intelligence (Seidel & Joschko, 1991), age (Corkum & Seigel, 1993; Grodzinsky, & Diamond, 1992; Hooks, Milich, & Lorch, 1994; Kupietz, 1990; O'Dougherty, Nuechterlein, & Drew, 1984), and gender (Matier-Sharma, Perachio, Newcorn, Sharma, & Halperin, 1995; Zentall, 1986) may also moderate children's performance on vigilance tasks. The relative magnitude of these effects has received scant attention, whereas their potential interaction with task variables such as target density and paradigm type remain unexplored and merit empirical scrutiny.

Collectively, past investigations and literature reviews provide persuasive evidence that task variables (particularly paradigm and target density) and subject variables may obscure interpretation of findings stemming from vigilance research in children (Corkum & Siegel, 1993; Loiser et al., 1996; Seidel & Joschko, 1991; Sergeant & van der Meere, 1990, 1994). Direct manipulation of task variables and exploration of both main and interaction effects are needed to address these concerns, but should be complemented by an analytic approach that examines the potential moderating effects of subject variables such as age, intelligence, and gender.

Overview of Study

The central purpose of the present study is to examine the manner in which select task variables (type of paradigm, target density) affect children's vigilance performance. Two distinct CPT paradigms were designed for this purpose with both administered using two levels (low, high) of target density. Paradigm selection was based on extant literature concerning differences between automatic and controlled processing tasks. The former are typically characterized as fast, parallel, and effortless contrasted with the slow, serial, and effortful attributes associated with controlled processing tasks (Fisk & Schineider, 1981). The conventional mapping dimension was invoked to distinguish between the two processes for purposes of designing the two paradigms. Consistent mapping conditions, which involve the selection of non-interchangeable target and distracter stimuli from different stimulus sets, are typically associated with automatic processing tasks (e.g., AX paradigm). In contrast, controlled processing tasks usually involve variable mapping conditions. Target and distracter stimuli are randomly selected from a common pool of stimuli and used interchangeably during task presentation (e.g., the BX paradigm wherein any letter that immediately repeats itself serves as the designated target and all stimuli serve as both potential targets and distracters).

Based on extant literature, it was hypothesized that standard measures of sustained attention (omission errors) would be affected primarily by the type of paradigm employed (AX versus BX), whereas commission errors would be influenced to a greater extent by differences in target frequency (low versus high target density). Complementary analyses were conducted to examine the potential moderating influences of children's intelligence, age, and gender on children's vigilance performance.

CHAPTER 2. METHOD

Participants

The sample consisted of 352 children (162 males, 190 females) between 6 and 15 years of age (Mean = 10.55, SD = 2.41) attending a public and private school in Honolulu (Oahu), Hawaii (see Table 1). Approximately 68% of the State's population and 90% of the population of Oahu reside in the city and county of Honolulu (U.S. Bureau of the Census, 1990). Schools were selected based on available data suggesting their ethnic and sociodemographic composition was a close approximation of children residing in Hawaii (State of Hawaii Databook, 1996).

Insert Table 1 about here

The public school is a research arm associated with the University of Hawaii whose primary mission is to develop and test curricula suitable for children of differing abilities and sociodemographic backgrounds. Children are admitted to the school based on ethnicity, gender, parent socioeconomic and marital status, residence location, and academic achievement to approximate the State's census.

A private school was selected for participation to obtain a sample reflecting the relatively large number of children attending private schools in the State (i.e., 16%). The school admits students from throughout the State, although the majority of children reside in the urban Honolulu area.

An informational letter, consent and demographic information form was mailed to parents of children attending both schools. The letter provided a basic description of the research project. The latter two forms were used to obtain written consent for children's participation and sociodemographic information concerning family members, respectively. Parental consent was obtained for 100% and 54% of the children attending the University-affiliated public school (participation is a required condition of admission) and private school, respectively. The obtained consent rate compares favorably with that reported in other studies based on school samples (e.g., Kearney, Hopkins, Mauss, & Weisheit, 1983). The ethnic composition of the sample was as follows: East Asian (36%), Part-Hawaiian (23%), Caucasian (11%), Southeast Asian (4%), Pacific Islander (<1%), and Mixed (25%). Subjects were considered "Part-Hawaiian" if their ethnic background included any Hawaiian ancestry. Subjects were considered "Mixed" if they could not be unambiguously assigned to one of the foregoing categories.

Instruments

Kaufman Brief Intelligence Test (K-BIT)

The Kaufman Brief Intelligence Test (K-BIT) consists of two subtests (vocabulary and matrices) designed to assess domains parallel to crystallized and fluid intelligence as described by Horn and Cattell (1966), and the verbal-performance dichotomy proposed by Wechsler (1991). Subtest scores combine to yield a composite IQ (mean = 110.18; SD = 11.83) that was used to provide an estimate of children's intelligence.

The psychometric properties of the K-BIT and expected patterns of relationships with other measures of intelligence are well established and detailed by Kaufman and Kaufman (1990).

Continuous Performance Test (CPT)

Two distinct CPT paradigms were programmed for use in the present investigation. The selection of paradigms was based on a comprehensive literature review that reflected their prevalent use by researchers and purported linkage to different modes of information processing (Sergeant & van der Meere, 1990). The paradigms included an AX (respond if "A" is immediately followed by the letter "X") and BX version (respond when any letter immediately repeats itself). The former is considered the less demanding of the two tasks and related to the automatic mode of information processing (i.e., characterized as fast, parallel, and effortless) contrasted with the more difficult controlled processing (i.e., characterized as slow, serial, and effortful) BX paradigm (Coons et al., 1981; Schachar et al., 1988; Sergeant & van der Meere, 1990). Identical task parameters were programmed for the two paradigms to include total test duration (three, 3-min consecutive blocks or 9-min test duration), stimuli (total number, size, and location of alphabetic characters), response mode (click mechanism on a track ball device), and target density (15 and 60 per 3-min block or 45 and 180 total targets per 9-min session in the low and high density conditions, respectively). Each paradigm was administered using a low and high density target condition to illuminate differences due to target prevalence. Basic parameters are described below.

AX version. The low and high target density AX version of the CPT used in the study require the child to respond (using the click mechanism of the track ball) each time the letter A is immediately followed by the letter X. Visual stimuli consisting of letters of the alphabet are presented in the center of the monitor screen (3.5 cm high, 3.5 cm wide) at 1-sec intervals (.2 second display, .8 second intertrial stimulus interval) throughout the 9-min duration of the test. Fifteen or 60 target stimuli (A followed by X) are randomly dispersed throughout each

3-min block of the CPT, with a total of 45 or 180 target stimuli occurring during the 9-min testing session for the low and high target density versions, respectively. Each 3-min block also contains 10 A stimuli not followed by an X, and 10 X stimuli not preceded by an A randomly distributed non-target distracters. A total of 540 letters are presented during the 9-min testing session in a quasi-random sequence (i.e., exceptions noted above).

BX version. The low and high target density BX or double-letter version of the CPT used in the study requires the child to respond (using the click mechanism of the track ball) on every occasion that an identical letter of the alphabet is displayed consecutively (i.e., repetitions of the same letter). All remaining task parameters with the exception of distracter stimuli (see above) were identical to the AX version described above.

Procedures and Instructions

Trained graduate students assessed children's performance on the CPT once per week over a 2-week period at the Children's Learning Clinic. The computerized CPT paradigms were administered as part of a larger battery of tests (e.g., intelligence testing, short-term memory) that required the child's presence for approximately 1.5 hours per session. Breaks were scheduled between tests to minimize fatigue. Each child was administered a total of four CPTs (AX-low density, AX-high density, BX-low density, BX-high density) across the two testing sessions (two each session, one week apart) in counterbalanced order. Within-day administration was scheduled such that a minimum of 45 min ensued between CPT tests.

Prior to beginning the test, children are required to: (a) identify letters of the alphabet to insure letter recognition, and (b) participate in 1-min practice sessions until a criterion of 80% correct target identification is met (for each CPT paradigm). A different, randomly determined sequence of letters and targets adhering to the identical experimental parameters described above was used during each successive testing session (i.e., pre-built into a CPT library file). Children were seated such that the computer monitor was approximately 0.5 m from the child with the center of the screen at eye level. An experimenter was present throughout all testing, situated approximately 3 m behind the child.

CHAPTER 3. RESULTS

A three-tier analytic approach was used to address the primary purposes of the study. In the first tier, omission and commission errors were examined using structural equation modeling to determine whether they represent psychometrically distinct constructs. The effects of task (CPT model, target density, time) and subject variables (age, IQ, gender) on children's omission and commission errors were examined in the second and third tiers, respectively. For these analyses, three age groupings (young = 6 to 8 years of age, mean = 7.5; middle = 9 to 11 years of age, mean = 10.1; old = 12 to 15 years of age, mean = 13.4) were formed based on extant literature suggesting that children's vigilance performance improves as a function of increasing age until approximately 12 years of age and remains relatively stable through early adolescence (Anderson et al., 1974; Gale & Lynn, 1972; Greenberg & Waldman, 1993). Two IQ groups (low IQ = 69 to 110, mean = 100.9; high IQ = 110 to 141; mean = 119.4) were formed based on a median split of the sample (note: random assignment was used to separate the multiple children with a 110 IQ into the two groups). This procedure was used so that intelligence could be included in the general model and allowed to interact with other task and subject variables while maintaining acceptable cell size based on recommended standards (Tabachnick & Fidell, 1996). In the final section, the two models (AX, BX) at each level of target density (low, high) are illustrated to facilitate comparison of omission and commission errors as a function of task variables.

Series 1 Analysis: Construct Validation

Latent variables (AX-low target density, AX-high target density, BX-low target density, BX-high target density) and their respective indicators (three time blocks: T-1, T-2, T-3) were modeled to form two, higher-order constructs (automatic and controlled processing) based on extant literature (O'Dougherty et al., 1984; Sykes et al., 1971). Structural equation modeling was subsequently used to evaluate the psychometric distinction between omission and commission errors – specifically, whether they are best considered as (a) a single construct wherein the two types of CPT errors are interchangeable (i.e., indicating that they can be combined for purposes of data analysis), or (b) distinct constructs that measure different psychological processes that require separate analysis (see Figure 1). All models were fitted to observed data using AMOS, version 4 (Arbuckle & Worthke, 1999). The distinct construct model (see Figure 1) showed good fit (omission errors: CFI = 0.992, RMSEA = 0.040; commission errors: CFI = 0.987, RMSEA = 0.044), whereas the single construct model failed to approximate actual relationships among observed scores.

Collectively, these results are consistent with extant research (Parasuraman, 1984; Sergeant & van der Meere, 1990, 1994; Warm & Jerison; 1984) indicating that omission and commission errors should be treated separately (i.e., not collapsed) when examining task and subject variable effects on vigilance performance.

Insert Figure 1 about here

Series 2 Analysis: Omission Errors

Omission Error Effects

Children's omission errors were analyzed using a 2 (AX and BX model) x 2 (low and high target density) x 3 (3, 3-min time blocks) x 3 (age groups) x 2 (gender) x 2 (IQ group) repeated measures analysis of variance. CPT model, target density and time served as within-subject (repeated measures), and age, gender and IQ served as between-subject factors. An alpha of .01 was established a priori for all univariate analyses.

A four-way interaction involving time x age x gender x IQ was significant (F[4, 678] = 4.050, p<.01), as was the three-way interaction involving model x target density x time (F[2, 339] = 20.178, p<.001). Two-way interactions involving model x target density (F[1, 340] = 306.484, p<.001), model x time (F[2, 339] = 71.767, p<.001), and model x age (F[2, 340] = 4.983, p<.01) were also significant, as were main effects for model (F[1, 340] = 957.103, p<.001), time (F[2, 339] = 172.968, p< .001), age (F[2, 340] = 159.279, p<.001), and IQ (F[1, 340] = 26.248, p<.001).

Time x Age x Gender x IQ Interaction

The 4-way interaction involving time, age, gender, and intelligence is illustrated in a 2-panel (males, females) graph (see Figure 2). Post-hoc analyses involving pair-wise contrasts (t-tests) of mean scores were conducted to elucidate the interaction effect. An alpha of .01 was used for all contrasts to provide balance for control of type I and type II errors.

Insert Figure 2 about here

The first series of post-hoc analyses was conducted to determine whether, within age groups (young, middle, older) and gender, omission errors differ for the two IQ groups (low, high) at each of the three, 3-minute time blocks. No significant differences emerged between low and high IQ groups for young boys (6-8 year olds) across the three time blocks (see Table 2). In contrast, low IQ boys in the middle age group (9-11 year olds) made significantly more omission errors than their high IQ peers at all three time blocks. Older boys (12-15 year olds) showed a nearly identical pattern to those in the middle age group with the exception of the first time block, which approached significance ($p<.05$).

The performance of girls within each of the three age groups but differing in IQ were contrary to those found for boys. Young girls (6-8 year olds) in the low IQ group made significantly more omission errors than high IQ girls of the same age across two of the three time blocks, whereas no significant differences emerged between low and high IQ girls in the two older age groups (9-11 and 12-15 year olds) over time. Finally, complementary analyses directly comparing boys and girls within each of the three age groups and with similar IQ revealed that older boys with low IQ made significantly more omission errors that older girls with low IQ during the second and third time blocks ($p<.01$). No other direct contrasts between boys and girls within identical age and IQ groups were significant.

Insert Table 2 about here

Collectively, this series of analyses indicates that intelligence interacts with an increased propensity for omission errors differently for boys and girls at different ages. Higher error rates are associated with lower IQ in 9 to 15 year old boys but not girls, whereas lower IQ is associated with higher error rates in 6 to 8 year old girls but not boys.

A second series of post-hoc analyses (t-tests) was conducted to examine whether children of different ages but with similar IQ differ in their frequency of omission errors. Unlike the preceding analysis in which IQ effects were examined in children of similar age, these analyses enable us to examine whether differences in age affect omission errors in children within a similar IQ grouping. Collectively, this series of analyses reveals clear and consistent differences in omission errors among young and older children regardless of gender or intelligence (see Table 3). The only exception to this pattern was for boys and girls in the middle (9-11 year olds) and older (12-15 year olds) age groups. Other than the lone significant finding for the first time block for middle versus older age boys, none of the contrasts for middle and older children were significant (i.e., indicating that their errors rates are not significantly different from one another). Thus, younger (6-8 year olds) boys and girls make significantly more omission errors than both middle and older age children, whereas the latter two age groups of children tend to perform relatively similar to one another.

Insert Table 3 about here

Model x Target Density x Time Interaction

Two analyses were conducted to examine the significant 3-way interaction involving model (AX, BX), target density (high, low), and time (three, 3-min time blocks) on children's omission errors. Pair-wise t-tests comparing the two CPT models and different levels of target density (AX-low, AX-high, BX-low, BX-high) at each of the three, 3-min time blocks revealed significant differences between each of the mean omission error scores at each point in time ($p<.001$ for all contrasts). The relative ordering of mean omission errors associated with each model x target density condition for each of the three time blocks is depicted in Figure 3 (note: each mean score is significantly different from every other mean score plotted for a given time block). Inspection of the figure indicates that children made significantly more omission errors under the BX model at both levels of target density compared to the AX model, whereas target density effects on omission errors appears to reverse itself across the two models (i.e., BX-low density > BX high density, AX-high density > AX-low density).

Insert Figure 3 about here

Analyses of trend were performed using error scores derived from the two CPT models (AX, BX) and two levels of target density (low, high) across the three, 3-min time blocks to examine the shape of the relationships among task variables and omission errors. The proportion of treatment variance (R^2_{Trend}) was computed for each trend component to elucidate the properties of the four CPT generated curves (Keppel, 1991). This analysis allows one to determine the relative contribution of each trend component (e.g., linear, quadratic) to a CPT curve when more than one component reaches statistical significance.

The shape of the relationships among CPT omission errors and the four generated curves (see Figure 3) was characterized by both significant linear and quadratic trends (see Table 4). Inspection of the table reveals that significant linear trends emerged for both curves associated with the AX model (low and high target density), whereas significant linear and quadratic trends were found for the two BX model generated curves. These results indicate that omission errors occurring under the AX model gradually increase as a function of time, whereas those associated with the BX (double-letter) model are steeper initially (i.e., during the initial 6-min of the task) and gradually increase thereafter. Thus, the significant target density x time interaction is best explained in the context of its higher-order, 3-way interaction involving CPT model effects.

Insert Table 4 about here

Collectively, this series of analyses indicates that both model and target density interact in affecting children's vigilance performance over time. Significantly higher error rates are associated with the double-letter BX than AX model at all points in time, and mean error rates rise more dramatically between the first and second 3-min time intervals under the BX double-letter than AX model regardless of target density. Conversely, target frequency interacts with the type of CPT model employed, with lower target frequency associated with higher and lower error rates under the BX and AX model, respectively.

Model x Age Interaction.

All other significant 2-way interactions and main effects were adequately accounted for in the context of their higher-order relationships with the exception of model x age effects. Mean omission errors for the AX and BX model by age are depicted in Figure 4. Post-hoc analysis (paired t-tests) revealed significant differences between all possible combinations of mean scores ($p<.0001$ for all contrasts), and inspection of the figure clearly shows the main effects of age and model (i.e., all children, regardless of age, make significantly more omission errors under the BX double letter than AX model). The significant interaction effect is due to the relatively greater change in overall errors under the AX than BX model for the different age groups (i.e., change in mean scores = 11, 9, and 7 for the young, middle, and older children, respectively).

Insert Figure 4 about here

In summary, the model x age interaction is trivial, accounts for a small percent of the variability in omission errors ($eta^2 = .03$), and is better explained by the main effects indicating that children in all three age groups perform more poorly on the double-letter BX than AX model.

Series 3 Analysis: Commission Errors

Commission Error Effects

Children's commission errors were analyzed using a 2 (AX and BX model) x 2 (low and high target density) x 3 (3, 3-min time blocks) x 3 (age groups) x 2 (gender) x 2 (IQ group) repeated measures analysis of variance. CPT model, target density and time served as within-subject (repeated measures), and age, gender and IQ served as between-subject factors. The 3-way interaction involving model x target density x time (F[2, 339] =5.373, p<.01) was significant, as were the 2-way interactions involving model x target density (F[1, 340] =176.406, p<.001), target density x age (F[2, 340] =17.774, p<.001), target density x time (F[2, 680] =47.006, p<.001), target density x IQ (F[1,340] =7.764, p<.01), and time x age (F[4, 680] =4.505, p<001). Significant main effects were found for model (F[2,340] =4.579, p<.05), target density (F[1, 340] =940.077, p<.001), time (F[2, 680] =20.739, p<.001), age (F[2, 340] =96.376, p<.001), gender (F[1, 340] =15.803, p<.001), and IQ (F[1, 340] =15.127, p<.001).

Model x Target Density x Time Interaction

Two analyses were conducted to examine the significant 3-way interaction involving model (AX, BX), target density (high, low), and time (three, 3-min time blocks) on children's commission errors. Pair-wise t-tests comparing the two CPT models and different levels of target density (AX-low, AX-high, BX-low, BX-high) at each of the three, 3-min time blocks revealed that children made significantly more commission errors under both high target density (AXH, BXH) than low target density conditions (AXL, BXL) regardless of model ($p<.001$ for all contrasts). Mean commission errors did not differ significantly for the two high target density models (AXH, BXH) during the first two, 3-minute time blocks, but were significant at the third time block ($p<.01$). In contrast, children made significantly more commission errors under the BX than AX low target density conditions consistently over time ($p<.001$ for all contrasts). The relative ordering of mean commission errors associated with each model x target density condition for each of the three time blocks is depicted in Figure 5.

Insert Figure 5 about here

Analyses of trend were performed using error scores derived from the two CPT models (AX, BX) and two levels of target density (low, high) across the three, 3-min time blocks to examine the shape of the relationships among task variables and commission errors. The shape of the relationships among CPT commission errors and the four generated curves (see Figure 5) was characterized by significant linear trends for the AX and BX high target density conditions (see Table 4), whereas no significant trends were found for low target density models (AXL, BXL). These results indicate that commission errors occurring under both the AX and BX high target density conditions increase as a function of time, whereas those associated with low target density (AXL, BXL) fluctuate minimally over time.

Target Density x Age Interaction

Mean commission errors collapsed across models, time, gender and IQ for each of the three age groups (6-8, 9-11, 12-15 year olds) are depicted in Figure 6-a to illustrate the target density x age interaction. Paired t-tests revealed significant differences in commission errors between each group under both low and high target density conditions, and within each age group between low and high target density conditions. Young children made consistently more commission errors than middle and older children, and middle age group children made more commission errors than older children under both low and high target density conditions ($p<.001$ for all contrasts). All children made significantly more commission errors under the high compared to low target density condition ($p<.001$ for all contrasts).

Insert Figure 6 about here

In summary, the target density x age interaction accounts for an insignificant percent of the variability in the data ($eta^2 = .09$) and is better explained by the significant main effects of age and target density as illustrated in figure 6-a.

Target Density x IQ Interaction

Mean commission errors collapsed across model, time, age, and gender are depicted in figure 6-b to illustrate the target density x IQ interaction. Results from paired t-tests indicate that children in the lower IQ group make significantly more commissions errors than their high IQ peers under high target density ($p < .001$) but not low target density conditions. Thus, the interaction between intelligence and vigilance related commission errors is observed only under the more demanding high target density conditions.

Time x Age Interaction

Mean commission errors collapsed across model, target density, IQ, and gender are shown in figure 6-c to illustrate the time x age interaction. Paired t-tests revealed significant differences in commission errors among the three age groups over time. Younger (6-8 years of age) children made consistently more commission errors than middle (9-11 years of age) and older (12-15 years of age) aged children, and children in the middle age group made more commission errors than older age children at each of the three, 3-min time blocks ($p < .001$ for all contrasts). Analyses of trend conducted to evaluate the shape of the three time x age curves shown in figure 6-c revealed significant linear trends for the middle and older aged children, and a non-significant trend for young children.

In summary, there is a clear developmental trend for vigilance related commission errors in children (6-8 year olds > 9-11 year olds > 12-15 year olds). Young children make more overall commission errors initially and maintain this error rate over time, whereas children in the middle and older age range show a gradual increase in errors over time.

Gender Effect

Significant main effects for commission errors were adequately explained in the context of their interactions with other variables with the exception of gender. Inspection of mean gender differences revealed that, overall, boys made slightly more commission errors than girls (boys mean CE = 51.94; girls mean CE = 49.80).

Omission and Commission Error Pattern Contrasts

Omission and commission errors for the AX and double letter BX model are illustrated in Figure 7 to facilitate comparison of error patterns. Inspection of the figure reveals clear differences between the two models and illustrates the degree to which target density influences performance both within and between models.

Insert Figure 7 about here

CHAPTER 4. DISCUSSION

The interplay among task and subject variables in the context of children's vigilance was scrutinized in the present study to facilitate derivation of hypotheses concerning the mechanisms and processes responsible for individual differences in children's CPT performance. Structural equation modeling was initially employed to determine whether CPT omission and commission errors represent distinct constructs and require separate analyses to explicate the potential interaction among task and subject variables. Results were consistent with previous suggestions (O'Dougherty et al., 1984; Sykes et al., 1971), and provide initial validation concerning the psychometric distinctness of the two CPT derived error scores.

Obtained results revealed both similarities and differences in the pattern of relationships among task and subject variables for omission and commission errors. Relationships associated with omission errors were generally more complex than those involving commission errors and nearly always involved model effects. Higher rates of omission errors were consistently observed under the double-letter BX than AX model (regardless of age), and error patterns associated with the two models over time were significantly different from one another. AX omission errors showed a gradual, linear increase over time, whereas errors associated with the BX model were characterized by an initial steep rise between the first and second time blocks, followed by a gradual rise thereafter (i.e., significant quadratic trend). These patterns held regardless of differences in target density, and provide robust evidence that the double letter model with it's associated controlled processing characteristics places greater demands on sustained attention and results in more rapid vigilance decay in children (Sergeant & van der Meere, 1990).

The interaction among model, target density, and time proved contrary to expectations based on past findings gleaned from the adult literature. High target relative to low target density conditions were expected to result in improved detection efficiency (i.e., fewer omission errors relative to the contrasting condition) for both models based on the signal probability hypothesis, by increasing signal probability and attenuating vigilance decay (See et al., 1995; Jenkins, 1958; Warm & Alluisi, 1971). Results confirmed this prediction for BX (double letter) omission errors, whereas contrary effects were found for the less difficult AX model despite incorporating identical target frequency parameters across models. These findings are not easily reconciled by a signal probability hypothesis, and are inconsistent with findings from a meta-analytic review that suggest that signal probability represents a non-perceptual factor and exert no influence on omission errors (See et al., 1995). The patterning of findings suggest that the unique demands of each task may interact differently with target density in affecting inhibitory control mechanisms, which in turn, influence vigilance accuracy. For example, inhibitory control under the double-letter BX model is constant and continuously invoked throughout the task (i.e., each stimulus letter must be evaluated and matched with the ensuing letter to determine whether to respond or not respond). Thus, increasing target density should result in additional but relatively minimal demands on the system and concomitantly improve arousal/alertness mechanisms that translate into improved vigilance accuracy (OEs) relative to low target density conditions as suggested by the findings. In contrast, inhibitory control mechanisms are only occasionally invoked under the AX model (i.e., only the letter "A" invokes a preparatory response). A fourfold increase in target density may disproportionately activate inhibitory mechanisms, and result in a significantly greater proportion of commission errors over time causing corresponding interference in evaluative processes (i.e., higher omission errors relative to low target density conditions). Additional research is needed to evaluate the potential interplay between these processes.

A clear developmental trend was observed in children's vigilance consistent with previous investigations involving CPT tasks, and supports the notion that the ability to sustain attention improves most dramatically during the early years and remains relatively stable as children approach adolescence (Greenberg & Waldman, 1993; McKay, Halperin, Schwartz, & Sharma, 1994). Younger children (6-8 year olds) make significantly more omission errors over time than older (9-15 year olds) children regardless of IQ and gender. Gender differences appear to be minimal across development. And, intelligence appears to contribute to children's ability to sustain attention in a different manner for boys and girls (i.e., lower IQ is associated with diminished ability to sustain attention in middle and older boys and younger girls).

Target density effects on children's commission errors revealed a consistent pattern of results. High compared to low target density uniformly resulted in higher rates of commission errors regardless of model (AX, BX), age (young, middle, older age groups), or intelligence (low, high IQ groups), and was characterized by a gradual linear decay over time. In contrast, commission errors under low target conditions showed no change over time (i.e., non-significant linear trend) irrespective of whether the task involved controlled (BX) or automatic (AX) processing demands. These findings are consistent with past investigations demonstrating minimal change or slightly improved commission error rates under low target density conditions, significant increases under high target density conditions, and improved inhibitory control with increasing age (Greenberg & Waldman, 1993). The findings are likely due to the stronger response set and correspondingly greater demands on response inhibition invoked under high target density conditions (See et al., 1995), and extend previous findings by demonstrating that children's ability to inhibit responding on a vigilance task also varies as a function of intelligence (lower IQ children experience greater difficulty with response inhibition), and gender (boys, overall, make slightly more commission errors than girls).

Clinical Implications

As a general principle, test scores used for diagnosis, monitoring of treatment response, or evaluation of outcome must be interpreted on the basis of well-established normative information. The evidence reported in the present study raises three special considerations. First, since CPT's that vary with respect to task structure (AX, BX) may measure different processes or constructs, norms should be developed separately for different instruments. Second, whereas norms for many psychological tests are typically based on age, the data demonstrate that vigilance performance is also significantly affected by intelligence and to a lesser extent, may vary by gender. Consequently, CPT norms should take IQ scores and gender into account as well as age, and with the latter, within-age comparisons may prove more fruitful that between group comparisons for investigating differences between children with ADHD and other clinical groups (Seidel & Joschko, 1990). It would also be helpful to researchers and clinicians if investigators report relationships among IQ, age, gender and CPT performance and the extent to which these relationships vary in pattern or magnitude across instruments. Third, implications of this research for model selection indicate that careful scrutiny and adjustment of processing demands (e.g., controlled, automatic) and target density dimensions is required, and must be guided by the intended use of the instrument. For example, the double letter BX model with high target density provides a balanced level of omission and commission errors in children, whereas the AX model with identical target frequency may prove more useful if one wishes to invoke a relatively higher percentage of commission errors to facilitate study of inhibitory processes. In a similar vein, either model under high target density may be appropriate for studying vigilance decay, whereas only the BX model is adequate for this purpose under low target density conditions.

Finally, generalization of our results to other settings, samples, and CPT findings may be limited by several factors. Our study involved a non-clinical, ethnically diverse sample of children residing in Hawaii and raises questions concerning possible differences in vigilance due to factors related to culture and ethnicity. The relative consistency of our findings with previous research suggests that such differences, if evident, are minimal but await cross-cultural investigations of children's vigilance. Consistent with the central thesis of this research, other parameters such as the length of the intertribal stimulus interval, overall stimulus display time, session length, stimulus regularity, and changes in other task parameters may affect children's vigilance and result in different findings from those reported herein.

Implications for Research

The practice of using CPT's interchangeably reflects an implicit belief that attention is a unitary and self-explanatory process. The result has been an excessive emphasis on its measurement and a concomitant lack of interest in establishing the cognitive mechanisms responsible for variations in vigilance performance within and across children. The functional nonequivalence of CPT's varying in task structure reported herein provides ample evidence that existing strategies are inadequate and require extensive revision. A potentially fruitful approach is to examine the manner in which CPT stimulus features (e.g., visual components of letters) are represented in working memory and how these features affect decisions about individual stimuli. This may facilitate characterization of the specific cognitive processes underlying performance on CPT's incorporating different target paradigms, and in turn, illuminate and clarify the mechanisms through which other task variables (e.g., target density, inter-stimulus interval) affect performance within and across target paradigms.

An additional line of inquiry that may prove useful is to scrutinize the parallels between task parameters affecting vigilance performance and variables that affect sustained attention in classroom settings. For example, the number of problems completed per page of assigned seatwork may affect attention to task in a similar manner and perhaps through the same cognitive mechanisms responsible for the relationship between target density and CPT performance. Research examining whether similar mechanisms operate to influence attention as measured in the laboratory and the classroom may help clarify why these different data sources are weakly correlated (Barkley, 1991).

Summary

Clinical concern with derivation of measures for assessing deficiencies of attention in children has emphasized measurement of the construct while ignoring theoretical and empirical analyses of the mechanisms and processes it subsumes. This is reflected in the widespread use of idiosyncratically designed continuous performance tasks and a corresponding paucity of research on the influence task and subject variables exert on children's vigilance. The review and empirical data reported in the present study demonstrate that a renewed emphasis on theoretical analyses of children's attention is warranted, accompanied by empirical studies concerning interactions among task and subject variables in the context of vigilance tasks.

Table 1. Sample Characteristics

Agegp	Age	Gender	N	IQ (Mean)	IQ (SD)
1	6 – 8	Male	39	112.10	11.23
		Female	51	107.49	9.05
		Total	90	109.49	10.23
2	9 - 11	Male	60	114.25	12.15
		Female	82	112.94	11.46
		Total	142	113.49	11.73
3	12 - 15	Male	63	106.29	11.29
		Female	57	107.30	13.01
		Total	120	106.77	12.09
Total		Male	162	110.64	12.08
		Female	190	109.78	11.64
		Total	352	110.18	11.83

Table 2. Omission Error Effects for Boys and Girls in Three Age and Two IQ Groups Over Time

	IQ	Time 1 Low vs High	Time 2 Low vs High	Time 3 Low vs High
Males				
	Young	ns	ns	ns
	Middle	***	**	**
	Old	*	**	**
Females				
	Young	*	***	**
	Middle	ns	ns	ns
	Old	ns	ns	ns

Note: ns = not significant; * $p<.05$, **$p<.01$, ***$p<.0001$. All significant differences indicate higher omission errors under low versus high IQ; Low IQ =110 and below; high IQ = 110 and above; Young = 6-8 years old; Middle = 9-11 years old; Old = 12-15 years old. Time 1 = first, 3-min time block; Time 2 = second, 3-min time block; Time 3 = third, 3-min time block.

Table 3. Differences in Omission Errors for Low and High IQ Groups of Boys and Girls of Different Ages Over Time

	Time 1	Time 2	Time 3		Time 1	Time 2	Time 3
Low IQ Males				High IQ Males			
Young vs Middle	**	***	***	Young vs Middle	***	***	***
Young vs Old	***	***	**	Young vs Old	***	***	**
Middle vs Old	***	ns	ns	Middle vs Old	ns	*	*
Low IQ Females				High IQ Females			
Young vs Middle	***	***	***	Young vs Middle	***	***	***
Young vs Old	***	***	***	Young vs Old	***	***	***
Middle vs Old	***	***	***	Middle vs Old	***	**	***

Note: Low IQ = 110 and below, High IQ = 110 and above based on median split of sample. Young = 6-8 year olds, Middle = 9-11 year olds, Old = 12-15 year olds. *$p<.05$, **$p<.01$, ***$p<.0001$, ns = not significant. Time 1 = first, 3-min time block, Time 2 = second, 3-min time block, Time 3 = third, 3-min time block.

Table 4. Trend Analysis Summary for Omission and Commission Errors

	F_{Lin}	R^2_{Lin}	F_{Quad}	R^2_{Quad}
Omission Errors				
AX-High Density	78.005***	.99	n.s	-
AX-Low Density	6.32*	.98	n.s	-
BX-High Density	51.461***	.69	216.18***	.31
BX-Low Density	283.515***	.70	55.81***	.30
Commission Errors				
AX-High Density	87.13***	.99	n.s	-
AX-Low Density	n.s	-	n.s	-
BX-High Density	43.80***	.98	n.s	-
BX-Low Density	n.s	-	n.s	-

***Note*:** The proportion of treatment variance (R^2Trend) was computed for each trend component to illuminate the properties of the four CPT generated curves (Keppel, 1991). This analysis allows one to determine the relative contribution of each trend component (e.g., linear, quadratic) to a CPT curve when more than one component reaches statistical significance. F_{Lin} = significance test of linear trend component; R^2_{Lin} = proportion of systematic variance accounted for by linear component; F_{Quad} = significance test of quadratic trend component; R^2_{Quad} = proportion of systematic variance accounted for by quadratic component. *p<.05; **p<.01; ***p<.0001.

APPENDIX B. FIGURES

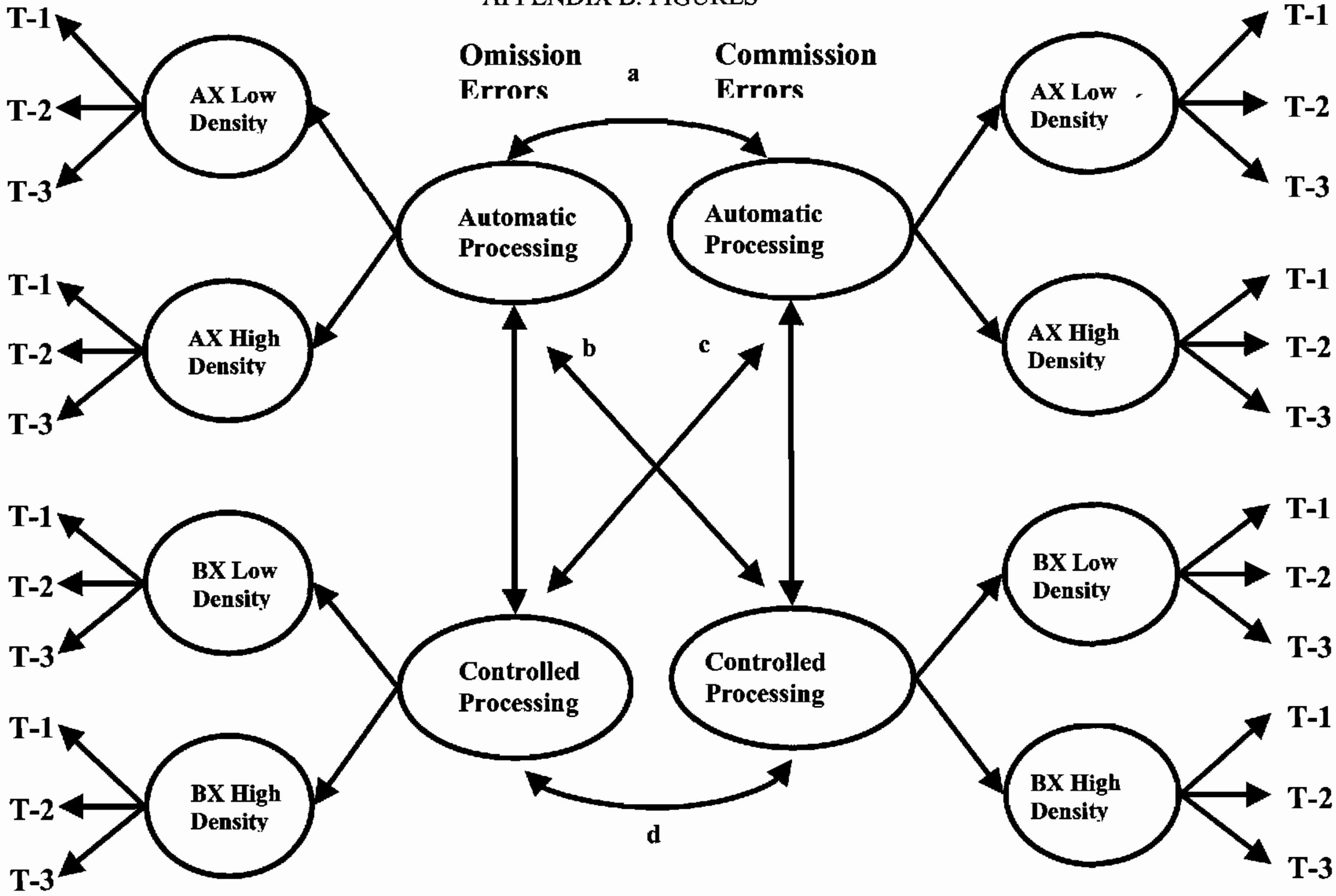

Figure 1. Structural equation model depicting the potential relationship between CPT omission and commission errors

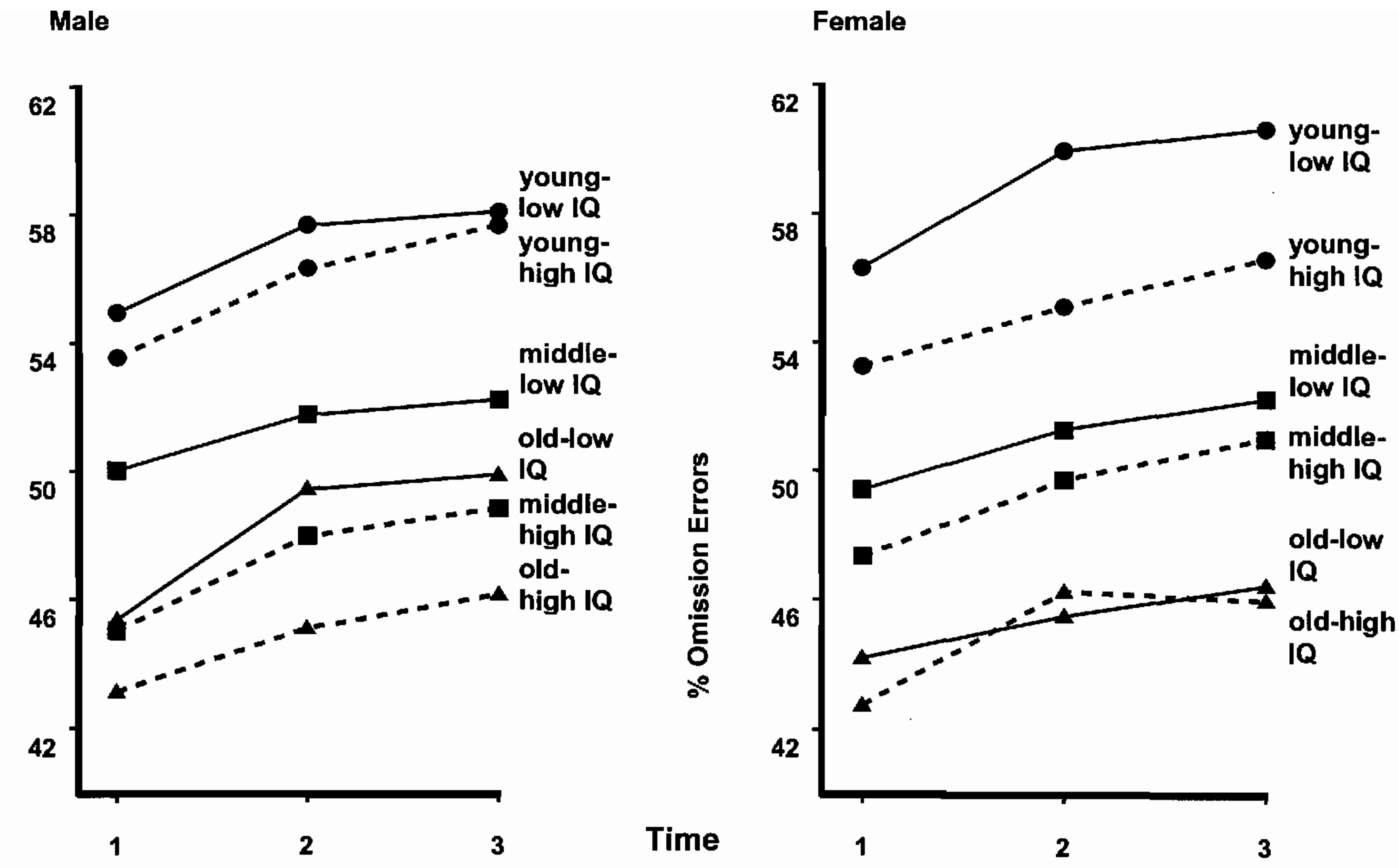

Figure 2. Mean percentage of Continuous Performance Test (CPT) omission errors: Gender x Age x IQ

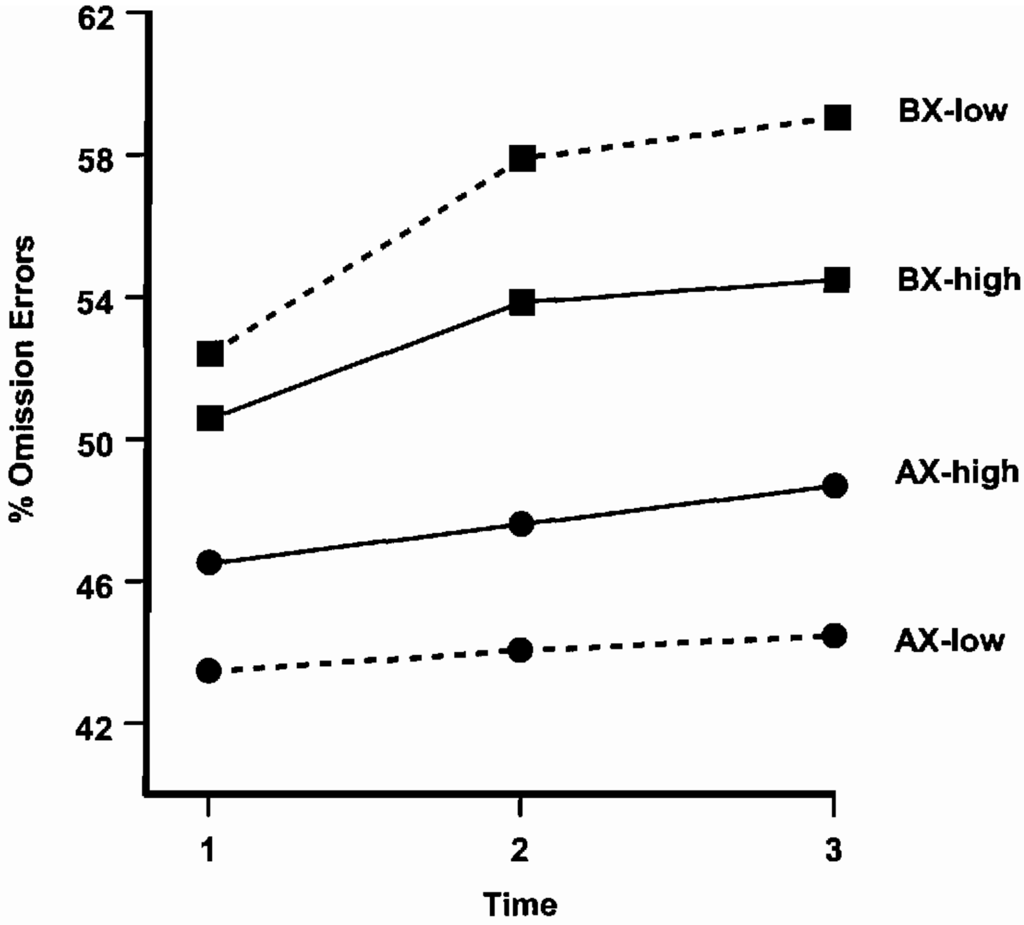

Figure 3. Mean percentage of Continuous Performance Test (CPT) omission errors: Model x Target Density

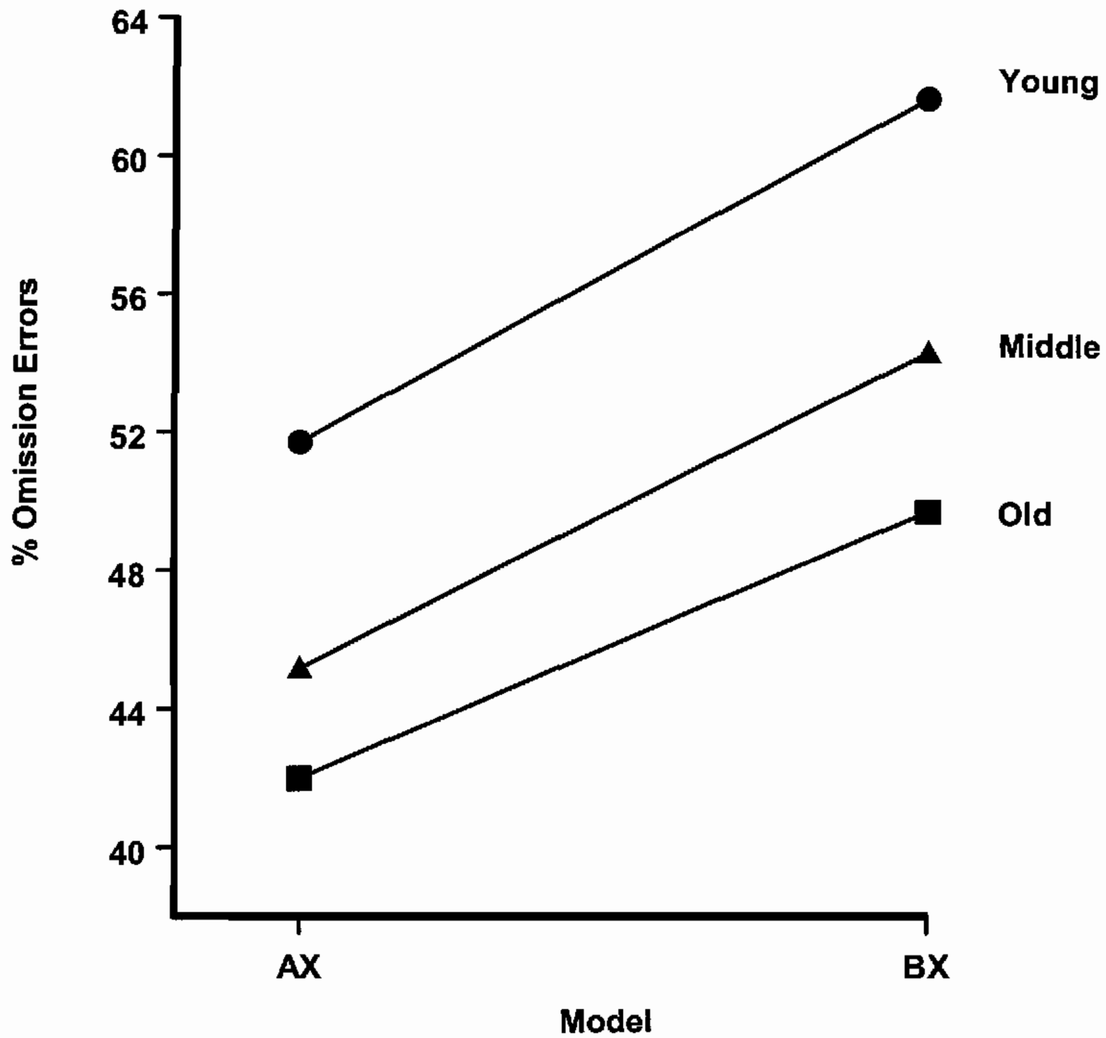

Figure 4. Mean percentage of Continuous Performance Test (CPT) omission errors: Age x Model

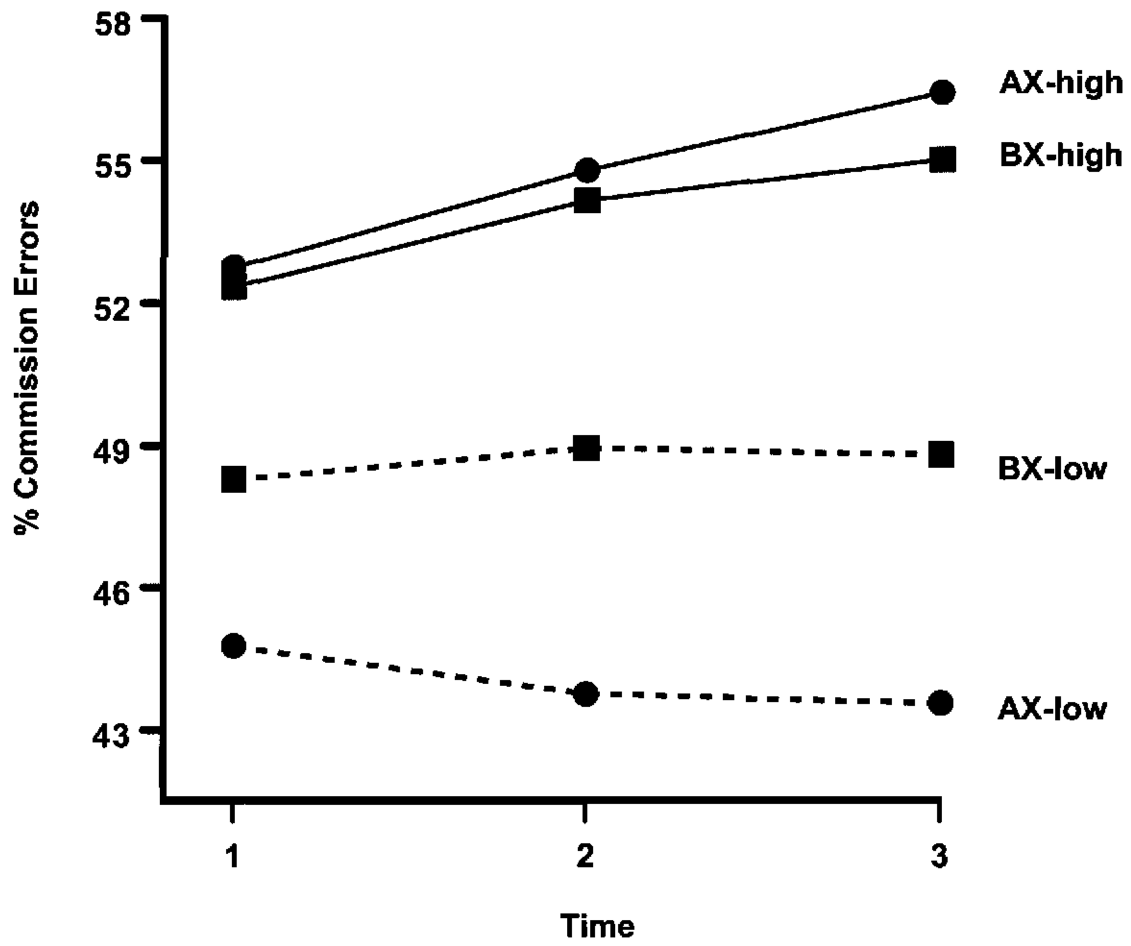

Figure 5. Mean percentage of Continuous Performance Test (CPT) commission errors: Model x Target Density

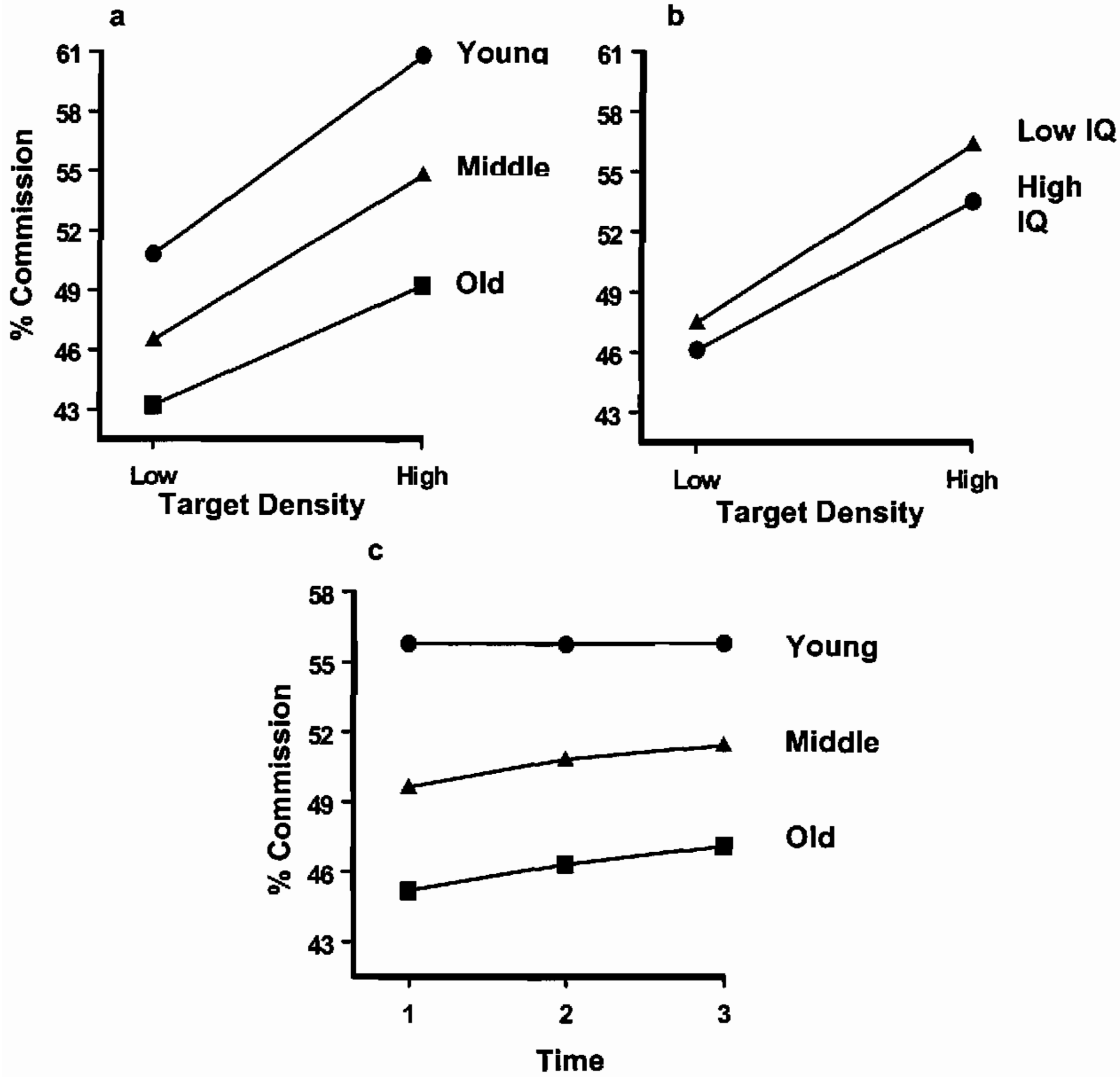

Figure 6. Mean percentage of Continuous Performance Test (CPT) commission errors: target density and age (a), target density and intelligence (b), and between age and time (c)

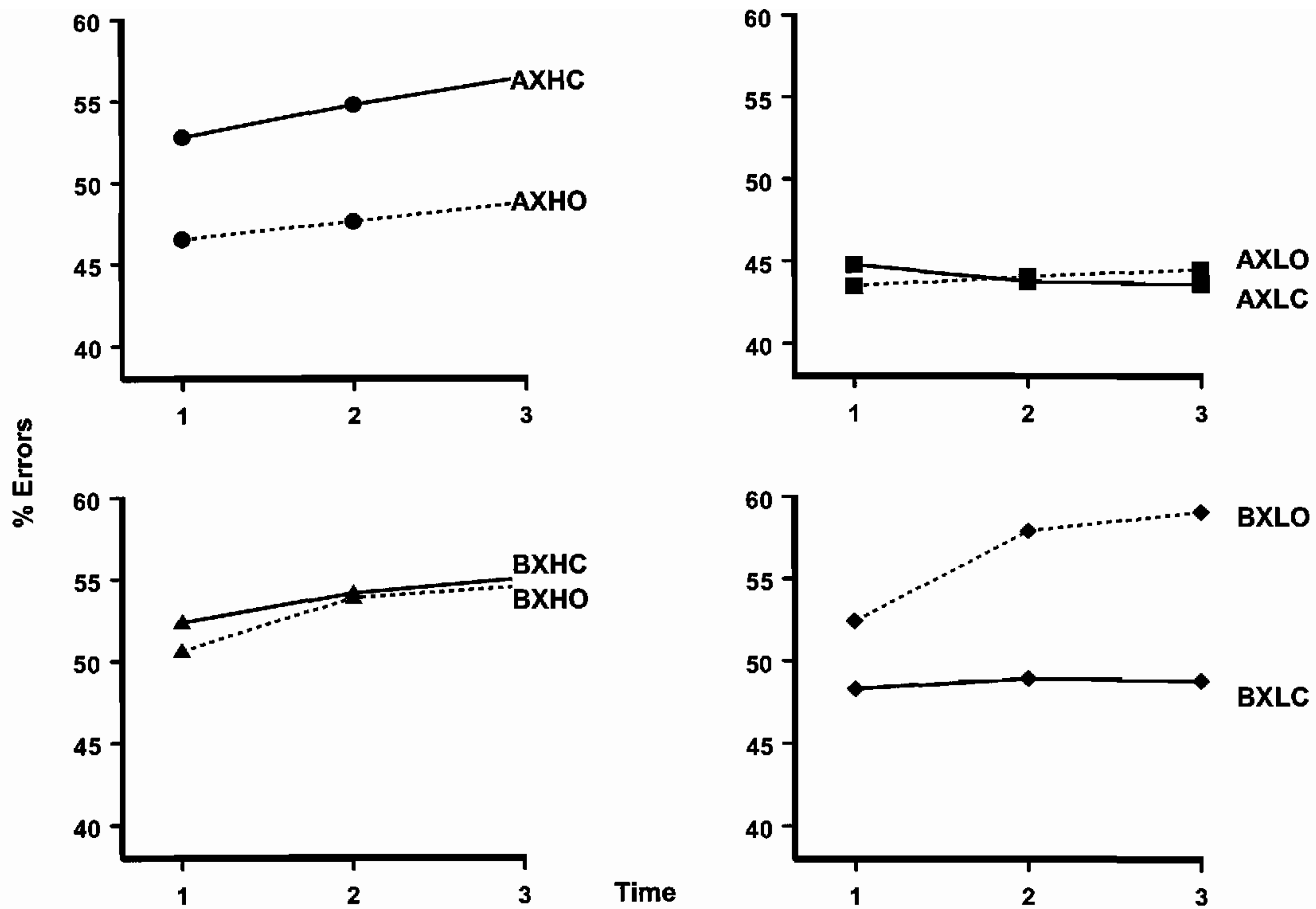

Figure 7. Mean percentage of omission and commission errors for two CPT models under two target density across 3 blocks

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