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Are psychophysical functions derived from line bisection reliable?

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Abstract

Psychophysical functions are used to characterize both normal perception and altered perception among patients with neglect, yet the reliability of these functions is rarely examined. The present study examined two-week, test-retest reliability for power functions derived from line bisection data among 58 normal, young and old, male and female subjects. Power function exponents and constants were, at best, moderately reliable over time. The size of the exponent tended to decrease at retesting. Reliability coefficients varied by age and gender; they were highly significant for young men, marginally significant for older men, and non-significant for women. Race influenced reliability as coefficients were significant for Caucasian subjects but not for African American subjects. Age and gender effects in this study parallel those in the literature on pseudoneglect, and they may reflect hemispheric differences in visuo-spatial processing, magnitude estimation, or both. (*JINS*, 2003, *9*, 72–78.)

Keywords: Crossover effect, Pseudoneglect, Neglect, Power function

INTRODUCTION

Our interest in the reliability of psychophysical functions derived from line bisection stems from our studies of unilateral spatial neglect (neglect). Neglect is defined as the inability to detect, report, or respond to stimuli located contralateral to a focal brain injury when the deficit is not due to primary sensory or motor loss (Heilman et al., 1985). Line bisection is both a neuropsychological method of assessing neglect (Heilman et al., 1985) and a psychophysical method of investigating magnitude estimation (e.g., length perception) (Baird, 1970). Patients with neglect classically misbisect lines on the side of true center ipsilateral to their brain injury, that is, contralateral neglect, but this interpretation was challenged during the last decade following the discovery of a seemingly paradoxical phenomenon known as the crossover effect (Halligan & Marshall, 1988; Marshall & Halligan, 1989). Crossover describes a pattern of performance on line bisection where longer lines are bisected consistently on one side of true center and shorter lines are bisected on the opposite side. Crossover is paradoxical because it is hard to explain how patients misbisect short lines on the contralateral side of true center if they neglect that portion of the line (Anderson, 1996; Chatterjee, 1995). Therefore, it has become increasingly important to resolve the crossover effect with contemporary theories concerning neglect (Bisiach et al., 1994).

It seems, however, that the crossover effect may stem from normally occurring errors in length estimation that are only exaggerated in patients with neglect. Several studies have served to clarify the crossover effect (Chatterjee, 1995; Mennemeier et al., 2002; Tegner & Levander, 1991). Interestingly, traditional psychophysical findings relevant to the study of magnitude estimation (e.g., systematic bias in length estimation) may provide the best interpretation of the crossover effect (Chatterjee, 1995; Chatterjee et al., 1994b; Mennemeier et al., 1998, 2002). It has been known for some time that when normal subjects estimate a range of stimulus magnitudes, such as a range of line lengths, they systematically overestimate stimuli of lesser intensity and underestimate stimuli of greater intensity (Hollingworth, 1909). Recently, it has been shown that these systematic errors in

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length perception correspond with the direction of errors on line bisection (Chatterjee, 1995; Mennemeier et al., 2002; Tegner & Levander, 1991). Among patients with brain damage, bisection errors contralateral to the side of the lesion correspond with overestimating the line's true length, whereas errors ipsilateral to the lesion correspond with underestimating length (Mennemeier et al., 2002). Among older normal subjects, line bisection errors left of true center correspond with overestimating line length, whereas errors right of true center correspond with underestimating length (Mennemeier et al., 2002). Patients with neglect differ from both normal subjects and patients without neglect in that both types of errors, length estimation and line bisection, become exaggerated (Mennemeier et al., 1998, 2002).

Congruent with the hypothesis that crossover can be explained in terms of systematic bias in magnitude estimation is the fact that line bisection errors are a power function of the physical length of the line (Chatterjee et al., 1994a, 1994b). A power function is a log-log plot of the data traditionally used in psychophysical studies of magnitude estimation to characterize the ratio at which perceptions of stimulus intensity change in response to the ratio of change in physical intensity (Stevens, 1975a, 1975b). Power functions are derived by log-transforming the data so they can be graphed as a straight line and by regressing estimates of stimulus magnitude on objective measures of magnitude. The resulting equation yields a line with a slope that is equal to the exponent of the power function and a y-intercept that is equal to the constant. The exponent summarizes the ratio at which perceived intensity changes in response to changes in objective stimulus intensity. The constant is typically described as a scaling factor, without greater elaboration on what constitutes a scaling factor (Stevens, 1975a; 1975b). In the case of line bisection, the exponent summarizes the ratio at which estimated line length changes as a function of the ratio of change in objective line length. Perfect estimation yields an exponent of one. Bias in estimation causes the exponent to deviate from one.

Whereas the exponent for length estimation is normally very close to one (Stevens & Galanter, 1957), it is significantly less than one among patients with neglect, and the power function constant is typically elevated relative to normal subjects (Chatterjee et al., 1994a). However, several patterns of change in the exponent and constant have been observed among patients with neglect. The exponent may be decreased without an appreciable change in the size of the constant. These patients tend to make ipsilateral bisection errors on long lines without a dramatic crossover effect on short lines. More typically, however, the exponent is decreased and constant increased in neglect. These patients show a crossover effect on line bisection and systematic overestimation of short lines and underestimation of long lines on direct measures of length estimation (Mennemeier et al., 2002). In contrast to patients with neglect, the relationship between power function parameters and line bisection performance is not as transparent among normal subjects. However, regression bias in the form of contextual effects, the tendency to overestimate lesser stimuli in a range of stimulus magnitudes and to underestimate greater stimuli, is common among normal subjects and, as in patients with neglect, this type of bias decreases the size of the exponent (Poulton, 1968, 1979).

Because the exponent and constant are used as both markers of normal perception (Poulton, 1968, 1979) and as indicators of altered perception in neglect (Adair et al., 1998; Chatterjee, 1995; Chatterjee et al., 1994a, 1994b, 1998; Mennemeier et al., 2002), it is important to identify factors that might influence their size. One such factor is change over time. Most studies of magnitude estimation make an implicit assumption that perception is stable, yet this assumption is rarely tested. A review of the psychophysical literature yielded only four relevant studies (McCourt, 2001; Mefferd et al., 1969; Pearson, 1922; Stevens & Guirao, 1964). One study of loudness estimation in normal perception (Stevens & Guirao, 1964) found a significant decrease in the size of the exponent upon re-testing at 1 to 6 months. Another study of vertical line bisection in normal perception found bisections to be nearly identical over a one-month interval (Mefferd et al., 1969). A third study of horizontal line bisection in normal subjects (Pearson, 1922), 20 sessions spanning a three-month interval, reported high test–retest reliability ($r = .94$). Finally, a fourth study of forced-choice tachistoscopic visual line bisection spanning 7–16 sessions found high reliability within subjects. However, test-retest reliability in these line bisection studies may not be directly comparable to those from studies for magnitude estimation. Only one line length was used in these line bisection studies (McCourt, 2001; Mefferd et al., 1969; Pearson, 1922), whereas studies of magnitude estimation are generated from a range of line lengths, typically between 6 and 10. Further, it is uncertain how the tachistoscopic method compares with the more traditional paper and pencil method of line bisection. No study, to our knowledge, has examined whether parameters of power functions generated from line bisection data are reliable over time. Therefore, to begin exploring this issue, the current study examined the reliability of power function exponents and constants derived from line bisection over a two-week test-retest interval among four groups of normal subjects—young and old, male and female. Age and gender were examined because a recent meta-analytic study of line bisection (Jewell & McCourt, 2000) showed that both age and gender can influence line bisection error. Further, phase of the menstrual cycle for young women and estrogen replacement therapy in older women were monitored because phase of menstrual cycle may influence line bisection judgement (McCourt & Olafson, 1997).

METHODS

Research Participants

Subjects ($N = 58$) were 28 university undergraduates, 13 female and 15 male (ages 18–30) recruited from undergraduate courses, and 30 elderly subjects, 15 female and 15 male (ages 60–85), recruited through participation in other research projects. They either received course credit or were paid for participation. Only right-handed subjects, without a history of either neurologic or psychiatric illnesses, were included because handedness has been shown to affect line bisection performance (Scarisbrick et al., 1987). To control for hormonal effects (Jewell & McCourt, 2000; McCourt & Olafson 1997), younger female subjects were tested once during the luteal phase of their menstrual cycle and once during the nonluteal phase, with the order counter-balanced. Only elderly females who were not on hormone replacement therapy were included.

Apparatus

Stimuli were lines of 10 lengths (.5, 1, 2, 5, 10, 20, 25, 30, 35, and 40 cm) and 1 mm in thickness presented on standard 11 by 17 inch white paper. One centered line was presented per page. There were three trials for each line length for a total of 30 lines per subject. Handedness was assessed using the Edinburgh Inventory (Oldfield, 1971) which asks respondents to indicate hand preference on 10 activities. The inventory yields a number ranging from −100 to 100. Negative numbers indicate left-handedness and positive numbers right-handedness.

Procedure

Procedures and recruitment techniques were approved by the University's Institutional Review Board. Each stimulus page was presented to the subjects with the midpoint of the line aligned with the subject's body midline. Lines were presented 30 cm in front of the subject. Subjects used their right hand to place a pencil mark at the midpoint of the line. The same procedure was repeated two weeks later.

Analyses

Test-retest reliability was analyzed on the exponent and constant of a power function using bivariate correlations. Power function exponents and constants were derived by regressing log-transformed estimates of length on log-transformed measures of physical line length using the least squares method. The exponent is equivalent to the slope of the regression line and the constant is equivalent to the y-intercept. Estimated line length was calculated as twice the distance from the right end of the line to the bisection mark for all subjects, consistent with previous studies (Chatterjee, 1994a, 1994b, 1995; Mennemeier et al., 2002). This method assumes that normal, right-handed subjects orient attention preferentially toward the right end of lines prior to bisection, secondary to a strong attentional vector of their left hemisphere (Kinsbourne, 1970, 1993). This assumption may be controversial (Barton et al., 1998; Chokron et al., 1998; Ishiai et al., 1989); however, the validity of our assumption concerning orientation is not critical to the purpose of this study. For the purpose of generating reliability coefficients, it makes no difference whether bisection errors are measured from the left or right end of lines as long as measurements are made in the same way at each test interval. Measurements were made to the nearest .5 millimeter. Differences in the size of the exponent and constant between test intervals were further analyzed for the entire sample and for each subject group separately using a matched-samples t test.

Finally, an average signed-percent error score was derived from line bisection for the purposes of comparing the reliability of mean bisection errors with that of power function exponents and constants. The distance between the subject's bisection mark and the line's true center was measured to the nearest .5 millimeter. Bisections to the right of center were assigned a positive value and bisections to the left of center were assigned a negative value. This error score was then divided by the line's total length to yield a percent value. Signed-percent errors were then averaged across all line lengths. Reliability coefficients were calculated for the mean signed-percent error scores as they were for the power function parameters.

RESULTS

None of the groups differed significantly on education or handedness score (Table 1). Young male and female subjects did not differ with regard to age, nor did older male and female subjects. Whereas older subjects were predominantly Caucasians, a much higher percentage of African-Americans was represented in the young subject groups, particularly in the female group.

Table 1. Demographics of study participants

				Race %	
Group	Age	Education	Handedness	Caucasian	African-American
Older Men	72.47 (4.09)	12.73 (3.28)	89.12 (21.48)	100	0
Older Women	70.13 (5.72)	12.93 (2.25)	94.44 (11.80)	93.3	6.7
Younger Men	18.80 (.94)	12.93 (.88)	82.04 (13.91)	73.3	26.7
Younger Women	18.77 (.73)	13.08 (.64)	82.94 (17.92)	38.5	61.5

Note. $n = 15$ for each group except younger women ($n = 13$).

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Test-retest reliability for the power function exponent was significant across all groups of subjects, but the correlation coefficient was low ($r = .44$, see Table 2). Variation was observed among groups. Correlation coefficients were significant for young men, were only marginally significant for older men, and they were not significant among women.

There was no difference in the size of the exponent or constant depending on phase of the menstrual cycle for young women. Comparing the size of the exponents between test intervals (Table 3) revealed a significant decrease over time ($t = 2.25$, $p = .028$); however, the effect was carried primarily by one group of subjects, elderly males ($t = 2.18$, $p = .047$).

Test-retest reliability for the power function constant was also significant across subject groups, but the coefficient was low ($r = .36$). Variation was again observed; reliability coefficients were significant for young men, marginally significant for older men, and non-significant among women. There was no difference in the size of the constant between test intervals ($t = -1.21$, $p = .231$).

Test-retest reliability for the mean signed-percent line bisection error scores paralleled that observed for the exponent and constant. The correlation coefficient for all subjects was low ($r = .43$) but statistically significant ($p <$ .001). Young men obtained the highest correlation coefficient ($r = .57$), followed by the older men ($r = .41$), and the young and older women ($r = .35$, for both groups). The size of the mean signed percent error was significantly different upon retesting for both young men, $F(3,56) = 2.6$, $p < .040$ and the older men, $F(3,45) = 3.2$, $p < .028$. For young men, the mean error score at time one was .27 ($SD = 4.3$) and at time two it was .85 ($SD = 5.5$). For older men, the mean error at time one was .22 ($SD = 5.05$) and at time two it was .01 ($SD = 5.5$). The size of the mean signed percent error score was not different upon retesting for young and older women ($p = .614$ and .366, respectively). Young women obtained a mean error score at time one of -2.10 ($SD = 5.4$) and a mean error score at time two of -1.85 ($SD = 4.78$). Older women obtained a mean error score at time one of $-.71$ ($SD = 4.6$) and a mean error score at time two of $-.72$ ($SD = 5.4$).

Table 2. Correlations of power function variables

Group	*r*	*p*
Exponent		
Older Men	.46	.082
Older Women	.33	.230
Younger Men	.71	.003
Younger Women	.29	.333
All	.44	.001
Constant		
Older Men	.48	.068
Older Women	.02	.951
Younger Men	.52	.046
Younger Women	.48	.094
All	.36	.005

Note. $n = 15$ for each group except younger women ($n = 13$) and all ($N = 58$).

Table 3. *T* tests for equivalency of power function components across trials

	Trial 1		Trial 2				
Group	*M*	*SD*	*M*	*SD*	*t*	*p*	*n*
Exponent							
Older Men	.9965	.021	.9851	.017	2.18	.047	15
Older Women	.9967	.013	.9933	.019	.69	.501	15
Younger Men	.9868	.010	.9827	.020	1.11	.284	15
Younger Women	.9905	.010	.9900	.011	.15	.884	13
All	.9927	.015	.9877	.017	2.25	.028	58
Constant							
Older Men	.0012	.028	.0124	.020	−1.70	.111	15
Older Women	.0053	.018	.0076	.020	−.33	.748	15
Younger Men	.0101	.014	.0107	.022	−.08	.905	15
Younger Women	.0165	.015	.0167	.015	.15	.938	13
All	.0080	.020	.0116	.019	−1.21	.231	58

Although race was not hypothesized to influence line bisection, it emerged as a potentially confounding variable because the racial composition of the younger age groups had unequal numbers of Caucasian and African American subjects. Therefore, additional analyses were conducted for younger subjects with race as a grouping variable, collapsing across genders. Test-retest reliability was significant for the power function exponent among Caucasian subjects but not among African-American subjects (Table 4), although the actual size of the difference between reliability coefficients was negligible.

Test-retest reliability was again significant for the power function constant among Caucasian subjects but not among African American subjects, and the size of the difference was larger than that for the exponent. The size of the power exponents and constants did not change between the two test intervals for either Caucasian or African-American subjects (Table 5).

Table 4. Correlations of power function variables across racial groups

Group	*r*	*p*
Exponent		
Younger African-Americans	.54	.069
Younger Caucasians	.52	.039
Constant		
Younger African-Americans	.33	.299
Younger Caucasians	.62	.010

Note. $n = 12$ for African-Americans and $n = 16$ for Caucasians.

Table 5. *T* tests for equivalency of power function components across trials across racial groups

Group	Trial 1 *M*	Trial 1 *SD*	Trial 2 *M*	Trial 2 *SD*	*t*	*p*	*n*
Exponent							
Younger African-Americans	.9852	.012	.9808	.019	.97	.353	12
Younger Caucasians	.9910	.007	.9900	.013	.35	.728	16
Constant							
Younger African-Americans	.0156	.015	.0198	.019	−.74	.473	12
Younger Caucasians	.0112	.014	.0083	.019	.78	.448	16

DISCUSSION

The parameters of power functions generated from line bisection data are, at best, moderately reliable over time. A number of factors influence reliability including gender, age, and race. Of these, gender has a relatively large influence with men tending to have higher reliability coefficients than women. Age has a secondary influence with coefficients highest among young men, marginally significant among older men, and non-significant among women regardless of age. Hormonal factors (i.e., phase of the menstrual cycle in young women) did not influence either the reliability or size of power function parameters generated from line bisection.

Race emerged as a confounding variable that influenced reliability, but race did not subsume effects due to gender and age. Only the young subject groups differed in racial composition, and reliability coefficients reached statistical significance for young Caucasian subjects but not for young African American subjects. However, gender differences cannot be explained by differences in the racial composition of groups because gender effects were observed among older subjects, the vast majority of whom were Caucasian. Further, gender and race appear to influence different power function parameters. Race influenced the size of constant more than the exponent, whereas gender had the opposite effect. The findings for race are intriguing *post-hoc* observations that require replication and further study.

It is unclear whether previous studies of test-retest reliability in line bisection (Mefferd et al., 1969; Pearson, 1922), which demonstrated nearly identical exponents over time, are at odds with the present study or whether the studies are simply not comparable. Power functions are derived from data on a range of line lengths, unlike previous line bisection studies which employed lines of only one length. A range of stimulus values introduces a type of regression bias in magnitude judgement known as contextual effects (Poulton, 1968, 1979) that might influence reliability. Contextual effects refer to the systematic overvaluation of lesser stimuli in the range of sensory magnitudes and to the systematic under-valuation of greater stimuli. Contextual effects alter the form of the power function causing a decrease in the size of the exponent (Cross, 1973). Studies using only one line length largely avoid contextual effects, and so they may not be directly comparable to studies using a range of line lengths. Further work is necessary to learn how contextual effects might influence the size and reliability of power function parameters over time.

Several findings of this study converge with previous investigations of magnitude estimation. First, the size of exponents in this study was close to one for all subject groups. One is the commonly accepted exponent for length estimation (Stevens & Galanter, 1957). Second, the size of the exponents and constants was similar for male and female subjects, consistent with a previous investigation of gender effects on length estimation (Verrillo, 1982). Third, the size of the exponent decreased over time, which is consistent with the only other study, to our knowledge, of test-retest reliability in magnitude estimation (Stevens & Guirao, 1964). Interestingly, 7 of 11 subjects in that study were male, and older male subjects in the present study were primarily responsible for a decline in the size of the exponent over time. Unfortunately, subject ages were not provided in the previous study for comparison (Stevens & Guirao, 1964).

The gender and age effects in this study also appear to converge with gender and age effects in a recent meta-analytic study of pseudoneglect in line bisection (Jewell & McCourt, 2000). Pseudoneglect describes a pattern of normal line bisection performance on standard length lines (e.g., 10 to 30 cm) where the mean bisection error falls slightly to the left of true center (Bowers & Heilman, 1980). Pseudoneglect is commonly explained in terms of bias in spatial attention (Bowers & Heilman, 1980). The right hemisphere is presumed to bias attention contralaterally, toward the left end of lines, resulting in a "pseudoneglect" of the right end. However, most studies of pseudoneglect have examined college-age subjects. Different patterns of "pseudoneglect" are observed when gender and age are considered. Males tend to error leftward compared to females, and older subjects tend to error rightward compared to younger subjects. In other words, pseudoneglect is most pronounced among young male subjects, similar to how the young male subjects in this study demonstrated the highest reliability coefficients for parameters of power functions generated from line bisection. Further, pseudoneglect is least pronounced in women, similar to how women in this study demonstrated the lowest reliability coefficients. The mean percent error scores in this study did not yield a classic pseudoneglect effect because they are derived from a much broader range of line lengths. However, the convergence of age and gender effects might indicate that pseudoneglect involves bias in length estimation, in addition to bias in spatial attention.

One might speculate that age and gender influence reliability in length estimation *via* lateralized asymmetries in hemispheric processing. For example, gender effects might reflect the hypothesis that women are less clearly lateralized with regard to visuo-spatial processing than are men (Franzon & Hugdahl, 1986; Grabowska et al., 1994; Voyer & Bryden, 1990). As a result, women may be less reliable at judging length. Additionally, age effects might reflect the hypothesis that the right cerebral hemisphere undergoes a more rapid age-related decline than does the left (Albert & Moss, 1988; Gerhardstein et al., 1998; Goldstein & Shelley, 1981). Accordingly, older male subjects may be less reliable than younger males when judging length. Alternatively, hormones may influence reliability. While we originally monitored hormonal influences associated with stages of menses in women, with no result, one might speculate at this juncture that testosterone in men has greater influence in the reliability of length estimation. Testosterone levels should be highest in men, particularly young men, and lowest in women. Testosterone may influence the manner in which length estimates are derived, leading to higher reliability coefficients in young men than in either older men or women.

On a final note, the size of the power function exponent was observed to drop over time. This finding is intriguing because a drop in the exponent indicates that magnitude judgement becomes biased with repeated exposure to test stimuli. The result runs counter to the intuitive notion that magnitude judgements might improve with practice. Therefore, reactivity to prior experience is another part of the instability of power function parameters generated from line bisection. The nature of this form of bias remains to be determined.

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