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Handedness and eye preference correlates with academic ability

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Abstract
Ever since Orton's work in the 1920's, handedness and eye preference have been studied as possible predictive factors for patients and students with learning disabilities. The present study was undertaken to clarify some of the recent research in this area, and to attempt to establish the statistical validity in a non-random sample of graduate students. A 25-question survey was developed to characterize handedness and eye preference at near and far, with the goal of comparing these to standardized test scores in eight academic subject areas. 400 surveys were distributed for self-reporting of handedness and eye preference. The survey was a combination of a proven handedness inventory, classic eye preference questions for sighting eye preference at far, and newly developed questions on near eye preference. Of the original 400 surveys, 199 were used for this study. 103 of these were completed by females, 96 by males. This was a return rate of 51% and is considered respectable for comparable surveys. The subjects surveyed were in the age range 20 to 45 with a mean age of 26. 54% were male and 46% female in the surveyed population. The survey results were tabulated using a modified version of the Oldfield's established technique. The individual surveys were then linked to each subject's Optometry Admission Test (OAT) scores in a non-name identifiable manner. The handedness, eye preference and OAT score data were examined using the appropriate T-Test to compare the means for significance. Gender was separated from the other variables in order to eliminate spurious results. After comparing all groups, there was one significantly different OAT subscore. Left-eyed males at far and near (n=26 and n=21, respectively) had significantly higher quantitative reasoning (math) scores than the right-eyed males (n=67 and n=69). These differences were significant to the p=0.05 level using a T-Test for small number statistics. The means of the scores differed by approximately 20 points between the two groups (345 vs. 325 and 347 vs. 324). No statistically significant correlations were found between OAT scores and handedness, crossed hand-eye dominance, mixed handedness (ambidextrality), extreme dextrality, mixed eye preference or refractive error. However, implications of this project and future research are discussed.

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Handedness and Eye Preference Correlates with Academic Ability

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In partial fulfillment for the Master of Education
Visual Function in Learning
at Pacific University

May, 1999

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ABSTRACT

Ever since Orton’s work in the 1920's, handedness and eye preference have been studied as possible predictive factors for patients and students with learning disabilities. The present study was undertaken to clarify some of the recent research in this area, and to attempt to establish the statistical validity in a non-random sample of graduate students.

A 25-question survey was developed to characterize handedness and eye preference at near and far, with the goal of comparing these to standardized test scores in eight academic subject areas. 400 surveys were distributed for self-reporting of handedness and eye preference. The survey was a combination of a proven handedness inventory, classic eye preference questions for sighting eye preference at far, and newly developed questions on near eye preference.

Of the original 400 surveys, 199 were used for this study. 103 of these were completed by females, 96 by males. This was a return rate of 51% and is considered respectable for comparable surveys. The subjects surveyed were in the age range 20 to 45 with a mean age of 26. 54% were male and 46% female in the surveyed population.

The survey results were tabulated using a modified version of the Oldfield’s established technique. The individual surveys were then linked to each subject’s Optometry Admission Test (OAT) scores in a non-name identifiable manner.

The handedness, eye preference and OAT score data were examined using the appropriate T-Test to compare the means for significance. Gender was separated from the other variables in order to eliminate spurious results.

After comparing all groups, there was one significantly different OAT subscore. Left-eyed males at far and near (n=26 and n=21, respectively) had significantly higher quantitative reasoning (math) scores than the right-eyed males (n=67 and n=69). These differences were significant to the p=0.05 level using a T-Test for small number statistics. The means of the scores differed by approximately 20 points between the two groups (345 vs. 325 and 347 vs. 324).

No statistically significant correlations were found between OAT scores and handedness, crossed hand-eye dominance, mixed handedness (ambidextrality), extreme dextrality, mixed eye preference or refractive error. However, implications of this project and future research are discussed.

KEY WORDS: Handedness, Eye Preference, Dyslexia, Learning Disabilities, Hemispheric Laterality
Biography of the Author

James Kundart received a Bachelor of Science degree in Astronomy and Astrophysics and a Bachelor of Arts in History from the Pennsylvania State University in 1993. He is a candidate for a Doctor of Optometry degree from Pacific University in 1999. James proudly serves as the National Student Liaison to the College of Optometrists in Vision Development for the 1998-1999 school year. He has applied for a residency in Visual Enhancement and Rehabilitation at SUNY State College of Optometry in New York City for the 1999-2000 academic year. After he completes his training, James plans to return to Nazareth, Pennsylvania to establish an optometric practice specializing in vision therapy. He currently lives in Portland with his wife, Suzanne Peppell, a Naturopathic Physician candidate, and three housecats.
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Laterality and Learning Disabilities

In every sense of the word, the cost of learning disabilities in our society is enormous. Educators expend a grossly disproportionate amount of their precious resources on them, and yet the students afflicted often suffer from the lower self-esteem that goes with putting in greater effort than their peers just to survive academically. Those students who decide not to struggle against their learning disability end up not reaching their potential at best, and become delinquents at worst.

Because the stakes are so high, any predictive insight into which children will develop learning disabilities would be most valuable both for students and for educators. The current definition of learning disabilities used for Title I federal funding is a two year difference in students' assessed achievement and their potential achievement. Therefore, by the letter of the law children must be in second grade before it is possible for them to be officially classified as learning disabled. While educators and parents are sometimes aware that a problem exists long before this, when doubt remains an early predictor would be highly useful.

There have been countless attempts in this century to find early predictors of learning disability. Proposed risk factors have included asthma, food allergies or vitamin deficiencies, migraine headaches, otitis media and prenatal anesthesia (Cron, in Garzia, 1996). But by far the single most influential model of the learning disability has been Samuel Orton's theory of laterality (1937). The present study was undertaken to demonstrate, through current literature and a new, improved survey battery, which parts of Orton's model are valid and which are not.

Orton Tackles Dyslexia

The umbrella term “learning disabilities” encompasses a wide array of educational obstacles. The best known (if most poorly defined) label for a learning disability is dyslexia. Short of post-mortem autopsies of dyslexics' brains in search of anomalous planum temporales, the diagnosis of dyslexia is one of exclusion (Flowers 1993). The long history of the use of the term has its roots in part in studies of handedness and brain laterality. In 1925, a neuropsychiatrist and pathologist named Samuel Torrey Orton used the term “dyslexia” to describe a learning disorder that specifically affects reading skill in otherwise intelligent students (Segalowitz, p. 166). He founded the Orton Dyslexia Society, and his ideas form the basis of spin-off organizations like the Orton-Gillingham Academy.

In Orton's original formulation, handedness and eye preference were looked to as indicators of a student's risk of developing dyslexia. Orton noticed that there were an unusually high percentage of left-handers or
ambidextrous children among those diagnosed as dyslexic. He also observed a high rate of crossed hand-eye dominance (as measured by which hand was used for writing and which eye was used for viewing in a monocular microscope) among students with reading disabilities.

This lead Orton to propose that children who are ambidextrous or crossed hand-eye dominant have the greatest risk for developing dyslexia. His reasoning was that ambidextrous individuals presumably have diffuse cerebral hemispheric lateralization of motor and sensory functions. To use lingo popular in today's media, this population would be neither "right-brained" nor "left-brained." As a consequence, Broca's language production and Wernicke's language comprehension areas would be delocalized in the brain according to Orton's original theory of dyslexia. This could lead to mirror-image perception of words read or written.

One of the many original therapies for dyslexics diagnosed by the Orton Society was training in use of a dominant hand and eye on the same side of the body. This is somewhat different than long-extant parental and educator pressure to eliminate left-handedness by negative reinforcement, while leaving eye preference alone. It is now known that coercion methods to change handedness are rarely effective in changing anything beyond preferred writing hand. What is less clear is whether the early Orton Society's efforts to teach unilateral dominance without regard to which side was dominant were well grounded.

**Laterality and Learning Disabilities Beyond Orton**

Today there is disagreement about the validity of Orton's intriguing hypotheses. On the supporting side are mixed handedness and perhaps crossed hand-eye dominance. There does seem to be some clinical co-occurrence of ambidextrality with reading and spelling difficulty (see "Annett's Right Shift Theory" on p. 8). Numerous researchers have found a correlation between crossed hand-eye dominance and "neuropathic, learning and reading disability, and dyslexic populations" (Delacatto, 1963, Porac, Coren and Duncan, 1980a). However, like the increased incidence of left-handedness in the mentally retarded population, this may be explained simply by statistics, as follows. Tersely put, if these populations, like the general population, start out mostly right-eyed (or handed) and suffer random hemispheric damage which changes their preference and learning ability, more pathological lefties will result (Segalowitz, p.149, see also p. 8 herein).

There are other laterality theories that disagree with Orton's assertion that strong unilaterality is best. One of these is the notion that equalized lateral skills give the student an advantage for learning. A proponent of strong bilaterality was noted optometrist G.N. Getman. Getman asserted that
"bilaterality is the foundation for binocularity," the latter being regarded as the crown jewel of the visual system.

Other researchers have found that consistent one-sided laterality among normals is less common than Orton believed. For example, crossed hand-eye dominance is now known to occur in 33% to 45% of the general population, most of whom do not have learning disabilities (Porac and Coren, 1976). This percentage may be even higher among professional baseball players, for whom there is an advantage to crossed hand-eye dominance when batting.

Orton's theory of reversals is also in question. Originally researchers believed that the mirror-image storage of visual information in each hemisphere simultaneously does not occur, but today many believe it does (Corballis and Beale in Segalowitz, 1976, ibid, 1983). However, this may not matter for letter reversals, since they have been shown to be common when learning to write and are not indicative of risk of later dyslexia. Because of this some (Eglinton & Annett, 1994) have called the evidence in support of Orton's theory "weak, contradictory and generally regarded as unreliable."

More recent literature has shown interesting trends with regard to hemispheric laterality and learning disabilities. In her literature review, Flowers (1993) has echoes of Orton when she suggests that left hemisphere functional deficits are the likely cause of dyslexia (as defined as a otherwise unexplained reading deficit). Her studies were done microscopically on neural tissue as well as macroscopically on language function. Annett, Eglinton and Smythe (1996) have reported a link between two distinct types of dyslexia (dysphonesia and dyseidesia) and hemispheric laterality patterns, as will be explained in more detail below (see Annett's Right Shift Theory, p.8).

Today, the Society which bears Orton's name does not stress his ideas about laterality, although there is a small handful of others in clinical practice who still do. Most notable among them are advocates of the Dolman & Delacatatto technique, which stresses the necessity of a hierarchical, linear development of neurological function and the necessity of strong lateral (left or right) preference (1963). Yet practitioners of the Dolman & Delacatatto technique are all but alone in the area of laterality remediation today.

Why were Orton's ideas about laterality and learning disabilities all but abandoned? One reason may be because the Orton Society has changed its emphasis from remediation of dyslexia to recognition and coping strategies. While examining the role of laterality in dyslexia is out of vogue with the Orton Society, there clearly are reasons to believe it might still have validity.

Overall, the jury appears to still be out on Orton. Even among nonbelievers, Orton's legacy may be partially responsible for the inclusion of
handedness data in almost all recent research in learning disabilities. The current research project has attempted to explore a heretofore unexplored avenue with may clarify in which ways Orton’s model was right. But first, the current understanding of hemispheric laterality needs to be reviewed.

**Two Sides of the Brain**

Since Orton’s time there has been rapid progress in the uncovering of differences in functions of the left and right cerebral hemispheres. This new research sheds much light on what might cause learning disabilities, as well as ways to teach students or remediate patients who have them.

The work begun by Broca and Wernicke on soldiers with specific head injuries has been opened wide most recently with the study of split-brain patients (patients whose corpus collosi were cut to treat seizures) and through the use of less invasive PET scan technology. As a result, intense interest has been focused on the differing functions of the two hemispheres. Just as Broca and Wernicke studied survivors of head injuries and brain tumors to uncover brain speech centers in intact patients, it is hoped that studying “split-brain” patients may help to clarify intact brain function.

Segalowitz (1983) has collected and condensed much of the research on hemispheric laterality and function in his monograph *Two Sides of the Brain*. It is best to forget what one has heard in the popular, often simplistic mass media about left and right brain function and objectively examine what is known. It is well established that there is a more or less clean division of motor function, with the right side of the body controlled by the left cerebral hemisphere and vice versa. For other behaviors, there may be a more subtle “dominance gradient” toward a particular side of the brain.

It has been found in split-brain patients that while there may exist an executive or dominant hemisphere, the most competent hemisphere is not always in charge of a particular task (Segalowitz, p. 83). In fact, it seems that the dominant side of a given individual’s brain may change based on the task performed. For most of us, the left-hemisphere is clearly dominant for language expression and understanding. The right hemisphere seems to be better than the left at identifying emotion and recognizing faces. Melody recognition seems to be dominant on the right as well -- in part explaining why those who stutter can often sing with fluency (Segalowitz, p. 201).

According to Segalowitz, “it appears that the right hand / left hemisphere system prefers a sequential, detailed strategy while the left hand / right hemisphere prefers a more global tactic for identification of a stimulus” (p. 49). In most people, verbal skills are more prevalent in the “left brain” (because of the location of Broca’s speech production area) while spatial skills are more prevalent in the right hemisphere. Thus it makes sense that
autism, with its characteristic noncommunicative mode of operation, may be at least in part due to left hemispheric damage (p. 203). Some reports also have shown illiterate adults to lose spoken language ability after damage to the right hemisphere (p. 153). However, the theory of complimentarity (that language and visual-spatial skills are in opposite hemispheres in normals) has been shown to be simplistic (ibid). This is because of gender differences in laterality, among other reasons (Sanders, Wilson & Vandenberg, 1987).

In a study by Gazzaniga and LeDoux (1970), the hemispheres both appear capable of sensory visual spatial tasks, but the left hand / right hemisphere system has a marked advantage in seeing complex, random shapes, identifying them by touch, and in tasks requiring motor manipulation (in Segalowitz, pp. 65, 72 and 50). Thus in clinical optometry, a copy forms task may be largely right-hemisphere regulated (Segalowitz, p. 49). For other forms of fine motor planning, coordination, timing, sequencing and even figure-ground, the “left hemisphere shows clear superiority” (ibid, p. 136, 177).

As was mentioned earlier, both hemispheres are likely used for visual memory, with the corpus collosum acting as a sort of mirror with regard to storage of the visual image in both a true and reversed sense (Corballis and Beale, 1983). Thus visual memory for left-right reversed forms takes on a new twist. Perhaps those with accurate visual memory are those who have consistent language access to the properly stored visual image.

Because of the split visual field (half of what is seen going to each hemisphere), both hemispheres register visual stimuli, but because of the unilateral location of Broca’s speech production area, the left hemisphere has much quicker verbal responses. The fact that a visual stimulus seen only by the right side can produce a verbal response at all is explained by the right side shuttling visual information over to the left via what Gazzaniga calls “cross cueing” (in Segalowitz, p. 51).

To what degree do neurologically intact people operate as if they have a split brain? Gazzaniga and LeDoux argue that because of the incomplete myelinization of the corpus collosum in childhood, at first “two selves develop somewhat independently, but in normals one side dominates for certain activities” (in Segalowitz, p. 59).

It should be well noted that certain behaviors which are popularly assigned to one hemisphere or the other are not to date found to have specific laterality. These behaviors include dreaming, poetry writing, music, art, or dance appreciation, mathematical or scientific skill, forensics and debating, imagination, intuition and creativity (Segalowitz, 1983). The division of tasks between the hemispheres is rarely that simple.
For example, while it may come as little surprise that there are a greater than expected number of left-handers among artists, music majors and architects, the higher than expected number of southpaws among lawyers, physicists and mathematicians causes one to question the popular notion that these are "left-brain" professions. In fact, the opposite may be true. Conversely, right-handers are most strongly represented among majors in accounting, finance, nursing and elementary education (Fry, 1990).

**What is Dominance?**

Handedness and eye preference are integral to Orton's theory. Therefore, to revisit this model of learning disabilities with a new, improved research battery, first one must define dominance.

When it comes to handedness and eyedness, what is dominance? According to prominent researchers Stanley Coren and Clare Porac of British Columbia, "dominance may be defined in terms of physiological preeminence, preferential usage, or behavioral priority" (1975). The same definition of dominance may apply when speaking of hemispheric laterality of the brain.

Different types of dominance have long been studied as an easy to obtain if imprecise measure of hemispheric laterality. The most common types of dominance to be examined are handedness, eye preference ("eyedness"), foot and ear dominance. Although all four of the above factors are crude ways to find hemispheric laterality, some of the four are better than others.

**Types of Eye Preference**

Eye preference was in favor as a probe of hemispheric laterality for a time, but because of the split visual field in each eye, has fallen out of favor in recent years. Porac and Coren (1978) have shown a poorer correlation of eye to hemispheric laterality (0.69) than hand and foot (0.87 and 0.84), but a better correlation than ear preference (0.56). They also found that males and right-handers have a stronger eye preference than females and left-handers. Porac and Coren conclude that "laterality of limb and laterality of eye do not appear to be correlated." This is likely due to cross-over of extraocular muscle innervation, midbrain nuclei, and "the partial decussation of the optic (nerve) fibers at the chiasm" before they reach the cerebral hemispheres (1975).

These same researchers have made use of twelve tests of ocular dominance. Among them are traditional determinants such as sighting through a tube, a cone and a hole card. Other more sophisticated tests include the ease of winking right eye versus left eye, visual acuity and color vision.
advantages, size differences (anisekonia -- the dominant eye sees an object as bigger in 67% of the subjects), monocular tachistoscopic speed, and fixating eye at near point of convergence break (1973, 1976),

From this research, Coren and Porac differentiate between a number of forms of ocular dominance, including sighting, sensory and acuity dominance (1973). They postulate that it is these different measures of ocular dominance that may explain the contradictory results in the literature regarding eye preference. Their terms sighting and acuity dominance are self-explanatory, but sensory dominance is not. Sensory dominance is defined by the researchers as which "input is preferred when the information the eyes take in is discrepant." The dominant sensory eye is also called the binocular controlling eye. It is the one "which takes the lead during complex binocular coordinations, while its contralateral partner functions in a secondary assisting capacity" (1979a).

Statistically, these researchers (1976) found that approximately 70% of the general population is predominantly right-eyed and 30% left-eyed.

**Types of Handedness**

Concerning handedness, it seems to be a unique phenomenon to modern humans. Hand or paw preference is not readily evident beyond random chance in other mammals, non-mammalian vertebrates or even early humans when taken as a group (Corballis and Beale, 1983). Moreover, once right handedness emerged in humans (which anthropologists tell us was coincident with the invention of tools), the percentage of left-handers has been reported between 7.2% and 14.5% (Benbow, 1986; Fry, 1990). Countless researchers have looked into why there is such a consistently low incidence of left-handedness among humans.

Handedness, like ocular dominance, is determined in part by the task performed. Some researchers, like Annett (1984), believe handedness is a continuous variable between left and right. Others, like Healey, Liederman and Geschwind (1986) have divided handedness into four factors: fine motor tasks (like writing or sewing), upper body programmed movements (like snapping fingers or pointing), proximal/axial factors (like swinging a bat or the first hand used in turning a cartwheel) and ballistic movements (like throwing a ball or dart). These four factors change the incidence of right-handedness but do not change the prevalence of dextrals for fine motor tasks.

In the 1930's and 1940's, Arnold Gessell and Louise Ames performed an expensive longitudinal study of handedness in children from birth to age 10. Using films made of the children, they concluded that handedness switches several times before becoming consistent at age two (Segalowitz, p. 117). Other researchers have used the age of 5 for lateralization, since complete
recovery from aphasia is very rare after this age, but possible before (Krashen in Segalowitz, p.110). Still, this does not reveal if the degree to which handedness is environmentally or genetically determined.

Coren, Porac and Duncan (1980a) performed a study among the "high trainable, low educable mentally retarded" consisting of 76 males and 62 females. They found there was a significantly higher incidence of left-sided or mixed-sided preference compared with two non-retarded groups of peers (60.9% right handed vs. 94.5% in the non-retarded group). They also found that maternal age at a child’s birth was predictive of later deviations from dextrality (right-handedness).

This raises the issue of pathological left-handedness. Note that it can be expected statistically that if most of the population is right-handed, then also most of the population that suffers brain injury or anoxia will be (originally) right-handed. If the hemisphere which suffers damage is random, still there will be more of these patients who have switched from right- to left-handed than vice-versa. Is this then where most left-handers and ambidextrous individuals come from?

Why do 23% of identical twins exhibit discordant hand preference (Segalowitz, p.148)? To answer this question, one must first understand the best theory of handedness proposed to date, the “right shift” theory of Marian Annett.

Annett’s Right Shift Theory

No hard evidence has been found for a handedness gene in humans or other mammals (Corballis and Beale, 1983; Porac and Coren, 1979; Porac, Coren, Steiger and Duncan 1980). In research using laboratory mice, the only conclusion that can be made concerning “paw preference” is that they are it may be congenital, but not genetic (Collins, 1975, in Annett, 1996). As Annett puts it, “random asymmetries are universal.”

In humans it has been shown that with 459 parent-offspring triads and 434 sibling pairs that the degree of handedness, but not the side preferred, may be genetically influenced (Coren and Porac, 1980a). In other words, two strongly right-handed parents are more likely to have a strongly left-handed child than a weakly right-handed one. Porac and Coren (1977) have also shown a behavioral influence of mothers’ handedness correlating to their children’s handedness. Fathers showed no such correlation, raising suspicion that if there is a genetic basis of handedness in humans, it could be X-linked recessive.

If there is indeed a “handedness gene,” why are only 7-15% of the human population generally regarded as left-handed, across cultures and
throughout recorded history? Is it simply a result of cultural pressure forcing those genetic lefties to switch? Even if the "left-handed" gene is recessive, Mendelian genetics predicts 25% of the population will be born left-handed.

Marian Annett of the University of Leicester in the United Kingdom has come up with the best genetic explanation of handedness distribution to date which satisfies the mathematical and epidemiological evidence. Annett founded her theory in 1972 by making "no assumptions that were not demanded by the evidence." Years of research later, Annett feels today that handedness is a continuous variable which has been long treated as discrete, leading to considerable contradiction in the literature.

Annett claims that a single gene is enough to explain handedness distribution in the human population (Annett and Kilshaw, 1984; Annett, Eglinton and Smythe, 1996). She identifies three sub-populations. First are some 32% of the population who are homozygous dominant for a "right (handed) shift," or "rs ++." A second, larger group makes up 49% of the population and is heterozygous genetically but still predominantly right-handed because the right shift is dominant. Thus this group has a heterozygous right-shift, or are "rs +-." The third and perhaps most interesting are the homozygous recessives. Annett has deduced that the opposite of a right shift is a lack of a right shift, rather than a predisposition to the left side. Annett asserts that this "rs negative" group makes up 19% of the population. Since they have no predisposition to either hand or hemisphere, the right-shift negative ("rs --") group are equally likely to be left- or right-handed for writing.

The implications of Annett's Right Shift theory are threefold. First, the majority of the population will be right handed, but among dextrals there will be at least three subtypes: the majority of dextrals who are "rs +-," a moderate number of extreme dextrals who are "rs ++," and a minority of ambivalent dextrals who are "rs --." Except for pathology, those who are left-handed will also be "rs --" and somewhat ambivalent about their handedness.

According to Annett, the presence or absence of this "rs" gene plays out in dyslexia. Annett examined two widely recognized types of dyslexia, namely dysphonesia (difficulty with phonetic pronunciation and spelling) and dyseidesia (difficulty with proper spelling and pronunciation of irregular words).

In Annett's dyslexia research, dysphonetics were uniformly missing the right shift, and were therefore "rs negative." Recall that the "rs --" population is ambidextrous and distributed equally among right- and left-handed writers (Annett, Eglinton and Smythe, 1996). This evidence is consistent with Lovegrove and Willows (in Garzia, 1996) who point out an automaticity or timing deficit in dysphonetics when reading. Such a timing deficit might
result from difficulty in accessing poorly lateralized information, just as Orton predicted. However, one can see that while strength of handedness may be predictive of risk of dysphonesia, knowing which hand is dominant for writing is not.

In contrast, Annett found those with dyseidesia (poor proper spelling but unaffected phonics) were strongly dextral ("left-brained"), and so likely had a right-handed shift and thus the hypothesized "rs ++" gene. In light of this, it makes sense that Maureen Dennis found dyseidesia absent in children who had had their left cerebral hemisphere removed due to brain disease. These children "seemed to function without much aid of phonics" and were, of course, left-handed (Segalowitz, p. 115).

All left-handers are not "rs --." Presumably, one can still be left-handed and be "rs positive," but this situation would require some kind of developmental interference. Most researchers would assign "pathological sinistrality" (or left-handedness) as the cause. In one very large (n=5161) study, it was found that "maternal age seems to predict deviations from dextrality...while paternal age and birth order do not" (Coren and Porac, 1980b).

This aside, it is perhaps easiest to identify the pathological left-handers by the strength of their aversion to using their right hand, eye or foot. What is important here is that it is not which hand is preferred but the degree of hand preference that is apparently inherited (Bryden, in Segalowitz, p. 148). Indeed, this is the best way to tell the two types of sinistrals apart. One group (those "rs --") will be somewhat ambidextrous while the other ("rs +--" or "rs ++" afflicted by early, resolved pathology) will have overwhelming preference for the left hand and foot, and presumably right cerebral hemisphere.

Other Theories on the Origin of Handedness

There are some competing theories to Annett's which might be useful to the educator or clinician. One is the "left-then-right" handedness theory of Young (in Segalowitz, p. 118). According to this theory, we are all lefties by default until the use of increasingly finer tools brings about right handedness. This theory is supported by the switch of hand preference seen in infants for various objects at specific ages. For example, according to Young, infants prefer to handle a cube with their left hands until 28 weeks, a pellet with their left until 32 weeks, and a bell with their left until 44-52 weeks. After those ages preference switches to the right.

Geschwind & Gallaburda (1985) have proposed a "testosterone hypothesis" of handedness. It says that "a mother may affect the laterality of her developing fetus indirectly by passing on a tendency for increased
sensitivity to testosterone" which slows the development of the left hemisphere compared with the right. Thus females would be less likely to become left-handed than males, since females are not normally exposed to excessive levels of this hormone. Benbow (1986) has hypothesized a connection of testosterone with left-handedness and immune disorders (allergies and asthma), and believes it could be due to testosterone effects on the thymus gland. This theory could explain the overrepresentation of males in the left-handed populations on both ends of the intellectual spectrum.

While the purported connection of sinistrality to allergies and asthma has been reported before, it has yet to be proven. It may in fact belong in the category of other allegedly connected disorders on the left-handed "laundry list," including alcoholism, Alzheimer's disease, diabetes, hair depigmentation, schizophrenia and tongue-rolling ability (Fry, 1990).

A third, complementary handedness theory to Annett's is the gradient theory of Michael Corballis and his colleagues (Corballis and Beale, 1983, Segalowitz, 1983). In this theory, which assumes no genetic component, the development of sophisticated language in humans has brought about handedness. There is some evidence that the development of human language is tied to a hand gestural system, as seen by the fact that people tend to gesture more with the right hand when speaking regardless of handedness for other tasks. While this may be a chicken-or-egg argument, if the "rs" gene cannot be found, it provides an organ-level backup within the framework of the rest of Annett's theory.

In summary, handedness may be determined by one or more of the following: random asymmetry in individuals, environmental or societal pressures, testosterone, pathology, trauma, or a right-shift biased gene. It is likely a continuous rather than discrete variable and is not solidified for the first few years of life. Of course, it is entirely possible that more than one or even all of these theories work in combination to explain human differences in handedness. Clearly, the issue is much more complicated than Orton knew in the 1920's.

Is Handedness a Reliable Measure of Hemisphericity?

If any form of Orton's model is to be used, the educator or clinician must understand the limitations identifying cerebral dominance with handedness. This is because handedness is not a pure measure of cerebral dominance.

One way to prove this point is to examine handedness and language function laterality using the Wada Test. The Wada Test is the use of sodium amytal to temporarily paralyze a hemisphere of the brain of the locally anesthetized patient. The awake patient can then respond to questions by the
researchers. Culminating twenty years of research by Rasmussen and Milner (1977, in Segalowitz, p. 143), 262 subjects whose handedness was known had the hemisphere on the same-side as their dominant hand paralyzed using the Wada Test.

By their ability to produce speech afterwards, it was determined in which hemisphere the patient’s Broca’s area could be found. Among right-handers, a minimum of 96% had Broca’s area on the left, with the remainder (4%) on the right. Among left handers, a minimum of 70% still had Broca’s area on the left, with the remainder split evenly between right-sided (15%) and, interestingly, bilateral (15%) speech production centers. Presumably, some of the same side hand-Broca’s individuals would exhibit a “hooked” writing posture (because of opposite hemispheres controlling language and writing). Hooked writing posture was self-assessed by the survey in question #13 used in the current study (see Appendix 1).

Speech production may be one of the most heavily lateralized brain functions, and the apparent strong preference of language production centers to the left hemisphere may not be reflective of the location of other functional brain centers. In addition, dominance seems to shift slightly to the right hand, foot, eye and left ear with age (Porac, Coren & Duncan, 1980b). All of these results serve to give the reader a grain of proverbial salt with which to take what follows.

Methodology

The goal of this paper was to study the correlation of handedness and eye preference with selected academic abilities, as measured by a standardized test. To probe these issues, a survey was developed to characterize handedness and eye preference at near and far, with the goal of comparing these to existing test scores. The survey is a combination of a proven handedness inventory, classic eye preference questions for sighting eye preference at far, and newly developed questions on near eye preference. When correlated with the test scores, the present study brings together a new combination of data with which to evaluate the Orton model of learning disabilities. The specifics of the survey and the results follow.

The Handedness and Preferred Eye survey (see Appendix 1) was distributed to 400 optometry students. The subjects were asked to use an identification number rather than their name on the survey. This provided confidentiality while allowing the researcher to recover entrance test scores to be correlated with each survey completed. The students surveyed were in the age range 20 to 45 with a mean age of 26. 54% were male and 46% female in the entire population.

Each 25-question survey was coded by the subject with an identification
number used to retrieve their Optometry Admission Test (OAT or entrance test) scores. The survey was exempt from informed consent regulations of the Institutional Review Board because the scores were already on file and were not used in a name-identifiable matter. The OAT scores are reported in eight parts:

1) Overall OAT  
2) Quantitative Reasoning (Math)  
3) Reading Comprehension  
4) Physics  
5) Biology  
6) General Chemistry  
7) Organic Chemistry  
8) Total Science (obtained indirectly from the previous 4 sections)

Each section of the OAT has a maximum score of 400 and a minimum score of 200. The mean for each of the eight areas is set at 300 points with a standard deviation of 30 points. Scores are rounded to the nearest multiple of ten in each section. If a subject had taken the OAT more than once, the most recent set of scores was used for this study. The scores on file had been sent directly from the OAT administrators and was not self-reported by the students.

On the first half of the survey, the subjects self-reported their handedness preference on a graded five-point scale for each of twelve activities. These first questions (1-12) formed the main handedness scale, and assessed much besides the dominant writing hand. Each of the first twelve questions were assigned a point score from 1 (left handed always) to 5 (right handed always). This yielded a total scaled score between 12 (extremely left-handed) and 60 (extremely right-handed). The first 12 questions were adapted from the Edinburgh Handedness Inventory by Oldfield (1971), a well-accepted measure of hand preference.

A thirteenth question asked the subjects to self-report their writing hand and posture. This question was designed to probe crossed hemisphere dominance for language with the assumption that those subjects would have a hooked writing posture (Coren and Porac, 1979).

Questions 14-17 assessed preferred eye for distance using four standard sighting eye dominance methods. Questions 18-21 attempted the same for preferred eye at near. It should be noted that no established method of determining near eye dominance exists, as it has been assumed previously that as with handedness, there is no switch in eye preference from far to near.

The eyedness questions were scored as follows. Each had five possible answers, graded on a 1-5 scale. Thus, a total score of 4 would indicate the
subject is extremely left-eyed, and a score of 20 indicates an extremely right-eyed subject at that distance. A score of exactly 12 would indicate the subject is neither right- nor left-eyed (ambiocular).

Four miscellaneous questions ended the survey. Question 22 (the needle threading question) had three possible responses which theoretically tested both handedness and eye dominance at near. Question 23 asked for the subject's gender, 24 for the number of left-handed blood relatives in the subject's immediate family, and 25 asked about the subject's refractive status. The final question was modified for 45 of the subjects to ask which, if either, is their most myopic (or least hyperopic) eye, with the assumption that this will be the near dominant eye.

Of the original 400 surveys, 204 were returned. Five surveys were either incomplete or did not correspond with admission test scores on file. The remaining 199 surveys were used for this study. 103 of the final number of surveys were completed by females, 96 by males. This was a return rate was 51% and is considered respectable for comparable surveys.

A note on self-reporting is in order first. Porac and Coren have found that offspring tend to significantly overestimate their parents right-handedness (1979b). This affects question 24 of the survey, in which the subjects are asked to report the number of left-handed, close blood relatives they have.

**Results and Discussion**

**All Subjects**

As mentioned previously, of the 199 surveys used, 103 were completed by females, 96 by males. Descriptive statistics of these data are found in Table 1, below.

The mean of all OAT scores is between 323 and 333 points, with a wider standard deviation for Reading Comprehension (40 points) compared with General Chemistry or the Overall OAT scores (about 25 points). The mean of handedness scores for the first twelve questions was almost 53 (moderately right handed). The mean of distance and near eye preference was moderately right eyed (a mean of about 15 out of 20 for each). The mean of the group’s refractive status (question 25) was closest to 2.50 D myopic but had high variation. This question was assessed for only n = 155, since the question was changed for the 44 remaining subjects in order to probe which eye had become more myopic due to preferential use at near.
Handedness and Eye Preference Correlates with Academic Ability

<table>
<thead>
<tr>
<th></th>
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<tr>
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</tr>
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<td>Refractive Status (n=1)</td>
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<td>1.11</td>
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</table>

Table 1 – Descriptive Statistics for Entire Data Set (n=199)

Other trends will be discussed in specific sections which follow. Note that a T-Test for either large or small number statistics, as appropriate, was used to determine the significance all correlations which follow.

**Gender**

103 of the subjects surveyed are female, 96 are male. Their data are shown in Table 2, below.
Table 2 -- Females (n=103) and Males (n=96)

Discussion

In overall OAT and General Chemistry scores, there was no statistically significant difference between the females and males. All scores for both genders had large standard deviations (between 23 and 41 points) and so were highly variable within a given gender. However, some trends can be seen.

In Quantitative Reasoning, Physics, Biology, Organic Chemistry and Total Science, the difference in the means was greater than or about equal to ten points in the males favor, and statistically significant at the p=0.05 level using a T-test. In Reading Comprehension, the females scored higher but the difference was not statistically significant. These differences in standardized
test scores are comparable to gender splits on similar tests. See Figure 1.

Figure 1 -- OAT Scores Split by Gender

n=103 Females, n=96 Males

Note that in this population the females tend to be slightly more dextral. The mean of the males' composite handedness score (for questions 1-12) is 50.7, slightly below the whole sample population mean of 52.6. The females' mean score comes in at 54.4, slightly above the population mean. Again, the standard deviations for each gender are large enough (about +/-12) to make this observation statistically insignificant. Likewise, eye preferences were not significantly different between the genders at near or far. Similarly, no other significant trends were seen.

In order to prevent the large differences in OAT scores between the genders from obscuring other more subtle trends, in all later sections the data for genders will be separated and only intra-gender comparisons will be done.

Handedness

For purposes of this study, the cutoff between right-handers and the rest was made at composite score on questions 1-12 of 53, corresponding to the score of a subject who was left-handed on at least two of the twelve items. This cutoff has been shown to divide the right handers from those with "a deviation from strong right-handed preference" (Fry, 1990). All those surveyed with scores on question 1-12 of 53 or greater were considered right-handed, and the rest considered left- or mixed-handed. Using these criteria, there were 148 right-handers and 51 others. The descriptive statistics in Figure 2 show the pertinent data for both the non-dextrals (non-right handed) and dextrals (right-handed). Question 13 correlated highly (over 83% correlation) with the scaled score for questions 1-12, and so was used mostly as a reliable adjunct to the earlier questions. See also Appendix 2.
Figure 2 -- OAT Scores by Handedness
Split by Gender

- Non-Dex. F. (n=18)
- Dextral F. (n=85)
- Non-Dex. M. (n=33)
- Dextral M. (n=63)

Discussion

With gender removed as a variable, there were no statistically significant differences in the OAT subscores between dextral and non-dextral students. Using a T-Test, there were some significant differences in the means of the dextrals and non-dextrals for eye preference on some individual items of the survey. However, as with other surveyed items, overall no trend was present correlating eye preference at a certain distance with handedness.

Eye Preference at Far

Distance eye preference was determined with four questions that have face validity. These questions, as well as their total scaled score, showed high correlation with each other (between 67.9% and 90.9%). There were 57 subjects who preferred to use their left eye at far, and 138 who preferred to use their right. The remaining 4 subjects scored a 12 on questions 14-17, indicating no eye preference at far (ambiocularity). There were 31 left-eyed females, 71 right-eyed females, 26 left-eyed males and 67 right-eyed males. See Figure 3.

Figure 3 -- Eye Preference at Far
Split by Gender

- Left Eyed F. (n=31)
- R. Eyed F. (n=71)
- Left Eyed M. (n=26)
- R. Eyed M. (n=67)
Discussion

It is interesting to note that there are roughly the same number of subjects who are left-eyed at far (n=57) as those who are not strongly right handed (n=51). They are not the same group, however as indicated by the mean score on the handedness questions (50.7 vs. 36.9). Eye preference was significantly different on all questions (both near and far) for both genders, indicating high correlation between far and near preferred eye.

There was one significantly different OAT subscore. Left-eyed males (n=26) had significantly higher quantitative reasoning (math) scores than the right-eyed males (n=67) to the p=0.05 level using a T-Test for small number statistics. The means of the scores were almost 20 points different between the two groups (345 vs. 325 points).

Eye Preference at Near

The data from questions 18-21 were scored the same way as for the distance preferred eye questions (14-17). The preferred near eye were not as reliable as those for far. It was found that two of the questions (#19, the eye used for a monocular microscope, and #20, the eye used to sight a pool cue) correlated highly with each other and the total scaled score (0.71 correlation or higher). Questions #18 (eye first used for ophthalmoscopy or retinoscopy) and #21 (eye used for reading monocularly) correlated less well (generally to the 0.4 level).

The size of the left-sided and right-sided groups are holding more or less constant at 50 and 137, respectively. There were 29 left-eyed females, 68 right-eyed females, 21 left-eyed males and 69 right-eyed males. The remaining 12 subjects showed no eye preference at near. They can be said to be ambiocular (their scaled scores were exactly 12). See Figure 4.
Discussion

This group is almost identical to the eye dominance at near group. Like them, the only statistically significant difference in OAT subscores was between the left-eyed males (n=21, mean score = 347) and the right-eyed males (n=69, mean score = 324). Using a T-Test and small number statistics, this was still a significant difference to the $p=0.05$ level.

Crossed Hand-Eye Dominance

Of the 199 subjects surveyed, 54 were found to have crossed hand-eye dominance. These subjects were either right-handed and left-eyed at far and near, or non-dextral and right-eyed at all distances. The subject population was chosen by comparing the scaled scores of questions 1-12, 14-17 and 18-21.

In this group, there were 25 female and 29 male crossed-dominants, and 61 female and 52 male unilateral dominants. The 32 remaining subjects could not be classified into either category due to ambiocularity or reversal of eye preference from near to far. The rest are compared intra-gender and the results are shown in Figure 5.

![Figure 5 -- Crossed Hand-Eye Dominance](image)

Discussion

No statistically significant differences were found between the two groups with regard to OAT subscores. The male crossed dominants were significantly less dextral than the non-crossed dominants. Also, there was a significant difference in eyedness near and far for both males and females, comparing crossed- and unilateral dominants. Even considering the surveyed sample is not truly random, these data are in direct contradiction to Orton's original theory that crossed-dominance is a risk factor for learning disabilities.
Mixed Handedness (Ambidextrality)

Of the 199 subjects who completed surveys, 40 were categorized as mixed-handed. These were the subjects who scored less than 53 (the mean) but greater than 19 on their scaled scores for questions 1-12. This group's data are shown in Figure 7.

**Figure 6 -- Mixed Handedness**

Split by Gender

- MH Females (n=13)
- Non-MH F. (n=90)
- MH Males (n=27)
- Non-MH M. (n=69)

Discussion

No statistically significant differences were found between the two groups with regard to OAT subscores. Also, no significant differences were seen in eye preference at near or far beyond random chance. As with crossed hand-eye dominance, above, these data are in direct contradiction to Orton's original theory that mixed handedness is a risk factor for learning disabilities, at least in this select population.

Extreme Dextrality

Of the 199 subjects who responded to the survey, 59 scored the maximum of 60 points on the first 12 questions. This means that these subjects reported using their "right hand always" for each of the 12 activities queried. Their data are shown in Figure 7.

Discussion

Once again, when compared to those who scored less than the maximum 60 points on the first 12 questions of the survey, there were no statistically significant differences in the OAT scores of this group. The same is true comparing the extreme dextrals to the entire population (split by gender). It is interesting to note that the mean handedness score of the male population drops from 50.7 to 47.8 once the 23 extreme dextrals are removed. The extremely dextral population tends to be right-eyed at far and near, is more likely to be female, and reports fewer left-handed relatives.
Handedness and Eye Preference Correlates with Academic Ability

Figure 7 -- Extreme Dextrality
Split by Gender

The extreme dextrals in this sample may represent Annett's homozygous dominant population ("rs ++"). Annett predicted these would be 32% of the general population, and in this sample the extreme dextrals represented 30%. 61% are female, which is consistent with the "testosterone hypothesis" of Geschwind and Galaburda (1985).

There were only two extreme sinistrals (those who scored the minimum of 12 points on the first 12 survey questions) in the sample population. By Annett's theory, extreme left-handers are not expected except in the case of transient pathology. Because of the small sample size no further analysis was done on this group.

Mixed Eye Preference (Switches Far to Near)

Of the 199 subjects surveyed, 17 (8.5%) switched eye preference in such a way. The rest either did not switch or had no eye preference at one or both of the distances (ambilocularity).

There was significantly more left-eyedness at all distances in the mixed eyed population than the larger group. The mixed-eyed population had fewer left-handed relatives than the mean (0.35 vs. 0.60 on question 24). Due to the small sample size, there was not a statistically significant difference in this group's OAT scores compared with the rest of the sample.

Refractive Status

Question 25 sought each subject's refractive status. 155 of the subjects were questioned about their refractive status. On the 44 remaining surveys, the refractive error question was changed to question about the subject's more myopic (or less hyperopic) eye. This was done in order to better determine the near dominant eye. The revised question turned out to have low correlation with the answers to questions 18-21 which involved near eye preference.
Further analysis was done with the original question 25 as answered by 155 subjects. Since the subjects were optometry students, their self-reported prescription power is more likely to be accurate. The subjects put their refractive status in one of five categories: high myopia, moderate myopia, low myopia, emmetropia and hyperopia. The responses were given a scaled score between 1 and 5, with 1 being the high myopia and 5 being hyperopia. During analysis, subjects who responded to question 25 with a scaled score of 3 or less were considered myopes, and the others were considered hyperopes. The subjects were also asked to report their stereopsis, however, inconsistent reporting led to leaving these responses out of this analysis.

OAT scores showed no statistically significant correlation with refractive status. The myopes did tend to be less right-handed (with a mean of 49.8 vs. 55.3 on questions 1-12) and logically had more left-handed relatives. Eye preference at far and near as well as gender showed no significant difference between the groups.

In the entire group's data, the non-dextrals seem to show slightly greater myopia than the right-handers. The left-eyed at near group showed less myopia than the right-eyed group at near, with mean scores of 2.9 and 2.6 respectively on question 25. These differences were not statistically significant.

**Summary**

In the sample surveyed, left eye dominant males had significantly higher quantitative reasoning scores than right-eye dominants at near and far. No other statistically significant effects were seen comparing handedness, eyedness and standardized test scores.

According to these data, non-dextrals have no significant advantage over dextrals on the OAT. Crossed hand-eye dominants and mixed-handed (ambidextrous) subjects also have no advantage or disadvantage on the OAT, contrary to Orton. Succinctly put, handedness and eyedness are not good predictors of success on the OAT with the possible exception of left-eyed males on quantitative reasoning.

Unlike eyedness, no statistically significant correlations were found between OAT scores and handedness for the non-random sample surveyed and analyzed in this study. However, from the literature there may still be a place for handedness in the screening for and assessment of learning disabilities. What follows is a synopsis of the extensive literature review given above.
Handedness and Eye Preference Correlates with Academic Ability

- Handedness comes in degrees and is not absolute.
- Nonetheless, about 85% of the general population is predominantly dextral or right handed.
- The dominant hand for writing has no relevance to academic ability.
- Left-handers in the general population are not disadvantaged academically. In fact, most studies find more left-handers in both intellectually handicapped and gifted groups.
- The higher percentage of left handers in the intellectually handicapped group can be explained by statistics, namely that 85% of those who suffer brain insult are originally right-handed (see p. 8).
- The best commonly done clinical test for eye preference is the near point of convergence break. The eye that retains fixation is the dominant eye at near.
- Eye preference is commonly opposite to hand preference (33-45% of the time). This is called crossed hand-eye dominance.
- Crossed hand-eye dominance has little or no relevance to academic ability, contrary to Orton.
- The subjects surveyed in the present study were a relatively homogenous group intellectually, and did not include outliers present in a truly random population sample.

**Implications**

There are some broad clinical and classroom implications of the literature reviewed in this study. A synopsis of these follows.

In any population, many of the sinistrals and some of the dextrals will be ambivalent about their handedness -- these are the patients or students who lack Annett's "right shift." There is clinical significance to this fact. Among those with reading or spelling difficulty, there are at least two distinct subgroups for whom laterality may be diagnostic.

According to Annett, we can expect the ambidextrous left- and right-handers to be more likely to have dysphonesia (poor phonetic ability) due to their incomplete language center lateralization. Even in those without learning disabilities, the reading teacher might be better off not stressing phonics to students who do not have a strongly dominant hand (Annett et al., 1996). This was the population on which Orton built his theory all those

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The strong right-handers who are learning disabled are more likely to have dyseidesia (poor irregular spelling ability without a phonics deficit). If the research is correct, this group is expected to make up about 30% of the general population and is more likely to be female. If their handedness is an indicator of their executive hemisphere, this population may have trouble copying forms since it is a predominantly right-hemisphere task. Visual-spatial tasks may have a gradient to the right hemisphere in most people and so may present this population with particular trouble.

Other forms of fine motor planning, timing, sequencing and figure-ground activities are mostly done in the left-hemisphere, according to current research. Proper recall without reversals may require dominance of the left hemisphere over the right if the patient’s Broca’s area is on the left, since visual memory seems to be a mirror-imaged two-hemisphere skill.

Some research suggests that students like to seat themselves in the classroom so that their eye movements towards the teacher, projector screen or chalkboard are also towards their dominant hemisphere. Also, students in special populations sometimes have conditions mediated by laterality issues. For example, patients or students with a stutter or autism are likely suffering from left-hemisphere dysfunction or damage, which may in part determine the strategies used for diagnosis, remediation and education.

It is wise to remember that sometimes a spelling deficit will be present without reading difficulty. Letter reversals may also occur but since they are a normal stage of development for beginning writers, they are not predictive of later dyslexia.

In this study, 8.5% of the subjects surveyed switched eye preference from near to far. This may be due to anisometropia (a difference in refractive error between the eyes). It is expected that when one eye is strongly preferred, the dominant eye will develop myopia faster than the least preferred eye. Perhaps this is why aniseikonic change is a reliable way to identify the preferred eye two thirds of the time, since it will see an apparently larger image.

In optometry, clinical uses of a properly identified dominant eye are fitting monovision contact lenses (with the dominant eye fit for near rather than far) and antisuppression training, particularly among alternating or intermittent strabismics. In fact, the efficacy of antisuppression training can be tested in a very short period on normals just by using the properly identified dominant eye (Porac and Coren, 1975b).
Future Research

Future researchers wishing to determine handedness by survey would benefit by using Annett’s Handedness Inventory (Annett, Eglinton and Smythe, 1996), which was discovered too late for inclusion in this paper. Because Annett’s work is ongoing and was built on Oldfield’s among others, it would be preferable to older surveys.

This study also found that self-reporting of eye preference, especially at near, is if anything less accurate than self-reporting of handedness for unusual tasks. More research is needed in the area of near eye dominance, particularly with regard to refractive status. In light of the very shaky relationship of eye preference to cerebral dominance, it would be beneficial to clarify the relationship between eye preference and learning disabilities, if indeed there is one. If the significant relationship between quantitative reasoning and left eye preference in males found in this study is repeatable, a model is needed to explain it.
References


Handedness and Eye Preference Correlates with Academic Ability


APPENDIX 1

THE HANDEDNESS
AND EYE PREFERENCE
SURVEY
HANDEDNESS AND PREFERRED EYE SURVEY

For questions 1-13, please try to visualize yourself doing each of the actions listed (even if you never actually do them) and indicate your hand preference using the following scale: a) left hand always, b) left hand mostly, c) either hand, d) right hand mostly, e) right hand always.

1) Hand used to hold a pen or pencil when writing.
   a.   b.   c.   d.   e.

2) Hand used to hold a pen or pencil when drawing.
   a.   b.   c.   d.   e.

3) Hand used to throw a ball or frisbee.
   a.   b.   c.   d.   e.

4) Hand used to hold a racquet when playing racquetball or similar game.
   a.   b.   c.   d.   e.

5) Hand used to shave or apply makeup.
   a.   b.   c.   d.   e.

6) Hand used to brush your teeth.
   a.   b.   c.   d.   e.

7) Hand used to hold a knife when cutting bread.
   a.   b.   c.   d.   e.

8) Hand used to hold a hammer when pounding a nail.
   a.   b.   c.   d.   e.

9) Hand used for turning a screwdriver.
   a.   b.   c.   d.   e.

10) Hand used to hold the match when striking a match.
    a.   b.   c.   d.   e.

11) Hand used to hold a comb when combing your hair.
    a.   b.   c.   d.   e.

12) Hand used to hold a spoon when eating with a spoon.
    a.   b.   c.   d.   e.

13) Indicate which of the following drawings below best describes the manner in which you hold a pen or pencil when writing:

\[ \text{Drawings} \]

Above questions adapted from R. Oldfield, Edinburgh Handedness Inventory, Neuropsychologia 9, 1971. (survey continues)
For questions 14-21, please try to visualize yourself doing each of the actions listed (even if you never actually do them) and indicate your eye preference using the following scale: a) left eye always, b) left eye mostly, c) either eye, d) right eye mostly, e) right eye always.

14) Eye used to sight a distant object through a hole in a flat card.
   a. b. c. d. e.

15) Roll this survey into a tube and sight the clock at the far end of the classroom. Which eye did you use to look through the tube?
   a. b. c. d. e.

16) Eye used for aiming the camera when taking a photograph.
   a. b. c. d. e.

17) Eye used to sight an archery bow.
   a. b. c. d. e.

18) Eye used first to look through a direct ophthalmoscope or retinoscope.
   a. b. c. d. e.

19) Eye used for looking in a monocular microscope.
   a. b. c. d. e.

20) Eye used to sight a pool cue.
   a. b. c. d. e.

21) Remove the square of translucent material attached to this survey and hold it in front of an eye while you re-read this question. Which eye does it feel most natural to leave uncovered?
   a. b. c. d. e.

Miscellaneous questions:

22) Which of the following pictures represents the way you would thread a needle?
   a. in front of left eye  b. along the midline  c. in front of right eye

23) What is your gender?
   female  male

24) Indicate the number of left-handed blood relatives you are known to have among your parents, grandparents and siblings.
   a. zero  b. one  c. two  d. three  e. four or more

25) Which one of the following best describes your refractive status?
   (circle more than one if applicable)
   a. myopia greater than 5 D  b. myopia between 5 and 2.75 D
   c. myopia between 2.50 and 1 D  d. within 0.75 D of emmetropia
   e. Hyperopia 1 D and up  f. Stereopsis < 50 arcsec (binocular vision)
APPENDIX 2

HANDEDNESS AND OAT SCORE

CORRELATION MATRIX
## Correlation Matrix

|          | OVERALL Q... | MA... | READING | PHYS | BIO | GEN CH... | ORG CH... | TOTAL SCI | Q 1-12 | Q 13 | Q 14 | Q 15 | Q 16 | Q 17 | Q 18 | Q 19 | Q 20 | Q 21 | Q 22 | Q 23 | Q 24 | Q 25 |
|----------|--------------|-------|---------|------|-----|-----------|-----------|-----------|-------|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| OVERALL Q... | 1.000 | .700 | .639 | .752 | .641 | .712 | .669 | .907 | -.104 | .130 |
| MATH     | .700 | 1    | .391 | .533 | .315 | .480 | .290 | .532 | -.120 | .125 |
| READING  | .639 | .331 | 1.000| .328 | .331 | .263 | .223 | .362 | -.052 | .080 |
| PHYS     | .752 | .533 | .328 | 1    | .337 | .504 | .511 | .793 | -.027 | .041 |
| BIO      | .641 | .315 | .331 | .337 | 1   | .401 | .326 | .679 | -.069 | .125 |
| GEN CHEM | .712 | .480 | .263 | .504 | .401 | 1.000| .473 | .757 | -.070 | .092 |
| ORG CHEM | .669 | .290 | .223 | .511 | .326 | .473 | 1.000| .757 | -.107 | -.052 |
| TOTAL SCI| .907 | .532 | .362 | .793 | .679 | .745 | .757 | 1.000| -.085 | -.107 |
| Q 1-12   | -.104 | -.120| -.052| -.027| -.069| -.095| -.070| -.085| 1.000| .834 |
| Q 13     | -.130 | -.125| -.080| -.041| -.125| -.074| -.092| -.107| .834  | 1    |
| Q 14     | -.019 | -.067| -.016| -.012| -.045| -.013| -.027| -.027| .103  | .064 |
| Q 15     | .013  | .055 | .034 | .015 | -.023| .031 | .011 | .003 | .105  | .094 |
| Q 16     | -.063 | -.095| -.036| -.110| -.116| -.009| -.049| -.099| .205  | .210 |
| Q 17     | -.047 | -.042| -.041| -.035| -.123| -.039| -.013| -.072| .168  | .181 |
| Q 14-17  | -.031 | -.071| -.003| -.047| -.084| -.001| -.021| -.053| .160  | .151 |
| Q 18     | -.140 | -.135| -.085| -.132| -.068| -.099| -.135| -.137| .396  | .321 |
| Q 19     | -.096 | -.118| -.055| -.096| -.101| .028 | -.089| -.099| .282  | .259 |
| Q 20     | -.067 | -.070| -.020| -.108| -.117| .021 | -.072| -.101| .195  | .233 |
| Q 21     | -.020 | -.016| -.065| -.066| -.014| -.034| -.069| -.052| .153  | .118 |
| Q 18-21  | -.100 | -.104| -.026| -.124| -.088| -.024| -.113| -.121| .320  | .292 |
| Q 22     | -.026 | -.071| -.062| -.015| -.008| -.032| -.131| -.056| .066  | .085 |
| GENDER   | -.176 | .191 | -.043| .240 | .139 | .087 | .183 | .226 | -.151 | -.105 |
| Q 24     | -.032 | -.059| -.003| -.102| .061 | .026 | -.106| -.054| -.048 | -.001 |
| Q 25     | .094  | .057 | .042 | .118 | .076 | .069 | .076 | .137 | .086  | .120 |

199 observations were used in this computation.
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