DISCUSSION
The main objective of the present study was to test the hypothesis of Annett's right-shift advantage theory about handedness and cognitive abilities and to verify the generality of the empirical findings of Annett and her co-workers. The balanced polymorphism with heterozygote advantage is difficult to study because there is considerable overlap between genotypes for hand preference and for hand proficiency, there is also the noise of individual differences in cognitive ability and the nature of human cognitive processes is quite complex. The psychological processes most influenced by balanced polymorphism with heterozygote advantage have not been identified. The present investigation may further indicate that it is not merely the presence or absence of a gene but the strength of the gene is relevant. These findings may also indicate if Annett's theory is valid and consistent, then cultural notions need to be revised for the proper development of cognitive faculties for the promotion of ambidexterity because in Indian culture we vigorously inculcate right-handedness.

The discussion will now revolve around three broad areas of handedness:

I. Distribution of handedness in local population
II. Estimating genotypes within handedness groups
III. Handedness and cognitive abilities
I. Distribution of handedness

Borod, Caron & Coeff (1984) stated that it would be reasonable to use a variety of measures to assess hand dominance as it allows us to compare the shapes and ranges of distribution and the use of continuous quantification allows finer graded comparisons. Using hand preference and hand proficiency measures on neurologically normal adults of Bostan area in U.S.A., Borod et.al. (1984) reported J-shaped distributions on preference measures and the distributions on preference measures and the distributions for left-handers and right-handers were generally normal on performance measures. Bishop (1989) reported similar distribution on hand preference scores and hand proficiency measures among students of Manchester University in Great Britain.

Peters and Durding (1978) using preference classes found a typically J-shaped distributions of hand preference. Porac & Coren (1981) pointed out that relative proficiency scores for most tasks follow a normal distribution, the typically distribution for hand preference is J-shaped, and ambilaterality is relatively rare.

The results of present study too revealed J-shaped distributions of hand preference scores (Figs. 4.1, 4.2 & 4.3) with a strong peak at the right most extreme, a less pronounced peak at the left most extreme and a relatively few individuals clustered around the neutral point. These results are in line with the findings of Peters & Durding (1978), Porac & Coren (1981) and Borod et.al. (1984).
Bishop (1989) explain why the distributions of hand preference are typically J-shaped. He assumed that the relationship between relative hand proficiency and probability that the superior hand is preferred on a task is not linear, but exponential. Where both hand are equally proficient, the probability of the left hand being preferred for a given task is 0.5. The probabilities of the better hand being preferred increase rapidly when there is a difference in proficiency between the two sides. Similar shape of the distribution in our local population, from whose group or sample varying in rs + genotype were drawn, attests to the fact that gene-pool and variation seem to be general. It further increases acceptability of the cross validation & cross comparisons of our finding.

The results further showed a bimodal distribution for proficiency measures (Fig. 4.4). The distributions of left-handers and right-handers on proficiency tasks was nearly normal. The results of this study concurred with the findings of Porac & Coren (1981), Borod et.al. (1984), Mc Manus et.al. (1993) and Resch et.al. (1997).

Proportion of males and females in the general population is not equal with respect to hand preferences. The results of present findings also revealed a greater proportion of right-handed females (Fig. 4.3) than right-handed males (Fig. 4.2). Proportion of females for the right hand preference was .77 and for males .71. It is also an oft repeated expression of the gene in population. One plausible explanation offered by Annett (1983) and Annett & Kilshaw (1983) is that the pattern of sex differences in the
handedness is due to a stronger expression of the rs + gene in females than males which make the females more dextrals than males.

II. **Estimating Genotypes within handedness groups:**

One problem confronting anyone trying to study handedness is that of measurement. There are many drawbacks in just relying on the layman's distinction between left-handed and right-handed. A simple dichotomy appears too insensitive. For those whose interest is in handedness as a manifestation of underlying biological constitution, it is desirable to find a way of assessing handedness which is relatively unaffected by cultural pressures. Thus, three approaches are prevalent on the basis of phenotypic expression of handedness (described in Introduction): Firstly, handedness questionnaires; secondly, hand proficiency and thirdly, the mixture of the two i.e. preference questionnaires and tasks assessing relative proficiency of the two hands.

It seems to be preferable to use direct assessment of proficiency, provided that practical consideration, such as the need to assess large number of subjects, do not make this expedient (Bishop, 1989). Taking all these points into consideration and assuring that preference and proficiency both measure the same underlying factor, present study sided with the third approach following duel criterion successive approach. The problem with this third approach is that proficiency and preference are measuring the same thing, is by no means universally accepted. The strongest statement against this position has been made by Porac & Coren (1981):
There has been a tendency to view skill, strength, and preference as relatively interchangeable indicators of the dominant hand; however, evidence suggests that they are separable aspects of behaviour perhaps mediated by difference mechanisms --- (The evidence) suggests that skill, strength (or general proficiency), and preference might be orthogonal dimensions.

The present study treated proficiency and preference as common indices of a single underlying factor and significant coefficients of correlation ranging from 0.57 to 0.74 were found out between hand preference scores (HS-I) and various hand proficiency measures (Table 4.4). Moderately high correlations and not very high correlations, thus revealed their separate significance and should not be treated one or another same.

In a series of different samples, Annett had repeatedly demonstrated a significant relationship between hand preference and relative proficiency of the two hands (Annett, 1983). If subjects were divided into groups according to strength of hand preference, then there was an almost perfect correlation between strength of hand preference and mean hand difference for that group on a peg-moving tasks (Annett, 1985).

Porac & Coren (1981), reported a number of facts which seem to be inconsistent with the view that proficiency and preference are determined by a common underlying factor. They reviewed the literature to show that when individual's scores for hand preference and relative proficiency were analysed, correlations though positive, are frequently far
from perfect. This point was also made by Todor & Doane (1977) who obtained correlations around 0.60 to 0.70 between various proficiency measures and degree of hand preference and concluded that questionnaires assessment of hand preference does not reflect hand superiority. Bishop (1989) found correlation of 0.63 between proficiency hand preference using a five-item proficiency scale and the correlation increased to 0.739 when a nine item proficiency scale was used. Thus, he predicted an imperfect agreement between proficiency and preference is very similar to that observed in experimental studies.

Annett's (1985) genetic model of handedness suggested that individuals differ primarily along a continuum which corresponds to differences in relative skill of the right-hands and left-hands, with preference being the secondary phenomenon whereas Mc Manus's (1991) genetic model proposed that individuals differ primarily in their hand preference and skill differences are only secondary phenomenon. Annett (1985) proposed three genotypes rs ++, rs +- and rs -- with the heterozygote being mid-way in the expression between homozygotes. Mc Manus et.al. (1993) suggested that left-handers might differ from right-handers for non-genetic reason, and should be excluded from the analysis. In the present study, the subjects were actually classified into putative genotypes following both the models (Annett's and Mc Manus's).

There are no major differences between the two models. The entire controversy would have been resolved had the genetics been in a position to actually locate and map the gene or genes responsible for handedness. Unfortunately, geneticists have not so far mapped such genes.
Sex differences only suggest its location on sex chromosome. However, cross-cultural generality and stability of sex differences are to be ensured first before restricting or focusing the search for a gene of handedness on sex chromosome. Thus, phenotypic method is also acceptable for the estimation of genotypes on the basis of location in the distribution.

III. Handedness and Cognitive Abilities

Handedness is defined as the differential or preferred use of one hand in a situation where only one can be used. Hand has been described as the most effective instrument of the mind. Skill in the use of man's hands has given many ascendancy over natural forces and it accounts for his intellectual evolution, his incentiveness and adaptability. Through the use of his hands man has created innovative tools for learning and achievement. Its influence extends to all spheres of life, and in the present study the role of handedness on various cognitive abilities, within Annett's and McManus's framework will be discussed.

The discussion will now revolve around the said hypotheses in the light of present findings.

(i) Handedness and Non-Verbal Intelligence

Since proportion of left-handedness in a population is a function of the number of rs −−, rs +− and rs ++ genotypes, so it was hypothesized that the groups will vary in intellectual ability. Non-verbal intelligence has been found to vary within handedness groups. The sample
was large enough to obtain each type of putative genotype. This was essential because the hypothesis under study concerned a genetic model of distribution in the population. The highest means were in the centre, for \( rs^+ - \) heterozygotes when the left-handers were included in the study. Means were significantly poorer to either side of this group (Table 5.3). There was significant quadratic component (Table 5.2). An inverted 'U' relationship between handedness and non-verbal intelligence was revealed when the means of handedness groups were graphically portrayed (Fig. 5.1).

Within the right-handed group, R1 group (right handers with the weakest bias to dextrality) scored significantly higher scores on progressive matrices than less strong dextrals (R2). However, R1 group scored higher than R3 group (strong dextrals) but it was not statistically significant (Table 5.19). The analysis also revealed a significant linear and quadratic components for handedness groups on non-verbal measure of intelligence (Table 5.18). Fig. 5.6 graphically portrays the trends in 'U' shaped fashion for the means of handedness groups on non-verbal measure of intelligence.

An overview of the results yielded by the analysis of variance, analysis of trends, Newman-Keuls Range Test of mean differences and graphical representation of means for different handedness groups lends support to our hypothesis of constant high performance on non-verbal intelligence in the heterozygotes \( rs^+ - \) or weak dextrals R1 group than the homozygotes (\( rs^- - \) & \( rs^+ + \)) or less strong dextrals (R2 group) and strong dextrals (R3 group).
Annett & Manning (1989) and Annett (1993 a) reported a significant linear trend with lower abilities for stronger degree of right-handedness and insignificant quadratic trend for matrices percentile in a sample of 5-12 years olds. Annett (1993 a) on the basis of corrected version (Annett & Manning (1989) concluded that children with mild bias to dextrality were superior to those with strong bias to dextrality on progressive matrices scores. Annett (1993 b) has shown that the chances of educational success in public examination were higher for children (12 and 16 years) with mild and moderate bias to dextrality then for children at each extreme. Crow (1995) supported Annett's theory using hand skill and academic ability. Tan (1991a,b); Natsopoulous et.al. (1992, 1998) also supported Annett's hypothesis of heterozygotic advantage for non-verbal intelligence.

Thus, handedness emerged as a significant effect in non-verbal intelligence as hypothesized that heterozygotes would manifest increased ability on non-verbal measure of intelligence.

Many small scale studies have investigated the relationship between handedness and intelligence (and/or talent), alongwith sex and familial sinistrality as moderating variables. O'Boyle & Benbow (1990) in reviewing the topic concluded that 'the variability of [the] findings speaks to the likelihood of type I error'. Several other studies have reported no heterozygotic advantage for cognitive abilities in general and non-verbal intelligence in particular. Mc Manus et.al. (1993) took a different view and concluded that the associations reported by Annett between hand skill
asymmetry and intellectual ability are not the result of heterozygote advantage but are consequences of some other variables.

Resch et al. (1997) reported a significant overall effect of handedness on hand skill difference and non-verbal intelligence measured by Cattell's Culture Fair Test (CFT - 20). They reported significant trend for a linear and significant quadratic effect, but the effects were not in the direction as predicted by Annett & Manning (1989) and Annett (1993 a). Cerone & Mc Keever (1999) reported no significant differences between the performance of hand preference classes on any of the four cognitive tests viz., Vandenberg Mental Rotation Test (VMRT), Stanford Identical Blocks Test (SIBT), the Shipley Hatford Vocabulary Test (SHVT) and the Word Fluency Test (WFLT)

(ii) Handedness and Verbal Intelligence

The effects of the difference in verbal intelligence between heterozygotes and homozygotes was assessed through General Mental Ability Test in Hindi (Jalota, 1976). It has three separate scales entitled verbal ability (V), numerical ability (N) and reasoning ability (R). GMAT - 'total' was also used as a measure of overall verbal intelligence. When the left handers were involved in the study (Annett's classification), handedness was found to be a significant source of variation only in reasoning ability of GMAT. A test for trends on handedness groups revealed a significant quadratic trend (Table 5.7). Annett & Kilshaw (1984) also found a significant quadratic relationship between hand skill and reading quotient.
Heterozygotes (rs + -) performed significantly better than rs -- homozygotes on reasoning ability scores (Table 5.8) when the means of handedness groups on reasoning ability were shown graphically, an inverted 'U' fashion curve was revealed meaning thereby highest scores for rs + - heterozygotes, lowest for rs -- group and moderate for rs ++ group (Figure 5.2).

When the left-handers were removed from the study (Mc Manus's paradigm), handedness groups emerged as a significant source of variation for GMAT - 'total' (Table 5.20), verbal ability (Table 5.22) and reasoning ability (Table 5.25). Weak dextrals (R1 group) scored significantly higher than less strong dextrals (R2 group) for GMAT - 'total' (Table 5.21), verbal ability (Table 5.23) and reasoning ability (5.26). Strong dextrals (R3 group) scored significantly better than less strong dextrals (R2 group) on GMAT- 'total', verbal ability and reasoning ability. Weak dextrals and strong dextrals did not differ significantly on any of the components of verbal measure of intelligence.

The results were further substantiated by the analysis of trends. Significant quadratic trends were also found for GMAT - 'total', verbal ability and reasoning ability. The means of the groups were graphically portrayed and a 'U' shaped curve was revealed for these three components of non-verbal intelligence (Fig. 5.7, 5.8 & 5.9).

Annett & Kilshaw (1984) reported superiority of rs + - heterozygotes over rs -- and rs ++ homozygotes and they obtained the

Natsopoulos et.al. (1998) tested subjects on a battery of language ability measures such as vocabulary, similarities, comprehension (WISC-R) deductive reasoning, inductive reasoning etc. They reported that handedness discriminated between right-handers (superior) and left-handers (inferior) in language ability. The results provided support to human balanced polymorphism advocated by Annett (1985, 1993).

Some other studies reported no heterozygotic advantage for verbal measures of intelligence. Mc Manus et.al. (1993) reported that heterozygotes were not intellectually superior to homozygotes on verbal I.Q. and vocabulary tests in a sample of undergraduate medical students. Crow et.al. (1998) reported that modest decrements were present in extreme right-handers and the most substantial deficits in verbal, non-verbal and mathematical ability were seen to the point of equal hand skill. For verbal ability females performed better than males, but the relationship relative to hand skill was closely similar for the two sexes.
Cerone & Mckever (1999) did not support the heterozygote advantage hypothesis for cognitive ability & suggested that visuospatial ability was modestly related to greater dextrality of participants.

(iii) **Handedness & Creativity**

The present study reported three significant handedness groups' difference out of five components of creativity when the left handers were included in the study and only one component of creativity i.e. creativity- 'total' when the left-handers were excluded from the study. Handedness groups emerged as a significant source of variation for creativity- 'total' (Table 5.9 and Table 5.27), elaboration non-verbal (Table 5.11) and originality verbal (Table 5.15). Significant quadratic trends were reported for creativity - 'total', elaboration non-verbal and originality verbal. However, linear as well as quadratic trends were significant for originality verbal component of creativity. When the left handers were excluded, there was significant declining linear trend for creativity - 'total'.

The rs + - heterozygotes performed significantly better than both the rs - - and rs + + homozygotes on composite creativity scores (Table 5.10) and elaboration non-verbal (Table 5.12). Heterozygotes (rs + -) significantly outscored rs + + homozygotes only on originality verbal component of creativity (Table 5.16).

Graphical portrayal of mean scores for these three components of creativity (Figs. 5.3, 5.4 & 5.5) showed an inverted 'U' fashion curve revealing thereby a heterozygotic advantage over homozygotes. Within the
right-handed group, when the means of creativity - 'total' for three handedness groups were plotted graphically and a linear declining trend was seen (Fig. 5.10), weak dextrals (R1) significantly obtained higher scores than strong dextrals (R3). Weak dextrals also scored better than less strong dextrals, but the results were not statistically significant.

Robert, Rosemarry & George (1983) found that creative individuals did not differ in cerebral preference or lateralization. Sharma (1986) reported that left- & right - handed males and females were not statistically different on non-verbal flexibility and originality dimension of creativity. Coren (1995) reported that handedness was not related to divergent thinking in females and left-handed males had higher divergent scores. The study further showed that the differences were not associated with superiority by left-handed subjects in convergent thinking. Atchley et.al. (1999) reported that both left and right hemispheres contribute to the maintenance of multiple word meanings in highly creative subjects, while less creative subjects show sustained subordinate priming only in the right hemisphere or no sustained subordinate priming. Cerone & Mc Keever (1999) found no heterozygotic advantage on Word Fluency Test, where the participants were required to say as many words beginning with the letter 'C' as she or he could in one minute, with proper names and variants of the same word disallowed.

(iv) Handedness and its interaction with sex

Interaction plays an important part in the interpretation of results for many basic experimental designs. None of the interaction effects
between sex and handedness on measures of cognitive abilities viz., non-verbal intelligence, verbal-intelligence and creativity were found to be significant.

Annett (1989) found no significant interaction between sex and handedness for the matrices percentile but reported a significant groups x sex effect for English scores. Annett (1992) also reported an insignificant interaction between handedness and sex for spatial ability. She reported a significant interaction for sex and handedness on Ray Complex Figure test. Palmer & Corballis (1996) reported an insignificant interaction between group and sex on Burt Word Reading Test. When the left-handers were excluded from the study, they found a significant sex x handedness effect for reading test.

The present findings support the earlier studies. Resch et al. (1997) reported an insignificant interaction between sex and handedness groups on Cattell's Culture Fair Test (CFT-20), a non verbal measure of intelligence. Cerone & McKeever (1999) found non-significant interaction between sex and hand preference classes for tests of cognitive abilities viz., SIBT, VMRT, SHVT and WFLT.

Contrary to hypothesis, "The interaction of sex and handedness groups on measures of non-verbal intelligence, verbal intelligence and creativity would be significant", the interaction of sex and handedness was thoroughly non-significant.
Overall evolution of rs + gene is in favour of verbal processing in the left hemisphere and a correlated pattern of right handedness is to reduce the time lack requiring inter hemispheric transfer of information. Generally commands are in verbal form and information reaches quickly to the motor areas of the hand within the hemisphere. It also reduces further chance of interference from other hemisphere (approximately 20 m.s.). As per Annett's advantage of heterozygotes must be at this cost. Cost is the increment in the reaction time and the advantages are collaborative and cooperative processing of both-hemispheres.

Mc Manus reported no such advantages of heterozygosity but her method of dividing the subjects into handedness groups differs from Annett's. It leads to attribute to the differences so obtained to this fact. Whereas the findings of the present study support Annett's contention even when the groups were formed as per Mc Manus scheme. Even though heterozygotic advantage was found with more vigour and generality in the sense that even verbal measures based on intelligence creativity were also higher.

Further departure observed was in the pattern of differences i.e. in the trends Mc Manus predicts a linear incremental trend whereas the data exhibit quadratic trend in the sense that heterozygotes show better scores and as the heterozygosity decreases the scores too but surprisingly again increases with homozygosity. This is perhaps due to the possibility of the quadratic trend emerges while following Mc Manus scheme, but no such possibility while following Annett's paradigm, where heterozygotes were compared with homozygotes.
This pattern of findings further suggest that in order to tap the trend in terms of strength of the rs + genes for speech laterality should be taken from different section of continuum. Such a scheme would include both the theories. So it is not merely the presence or absence of the gene, but the strength of the gene may be relevant.

The data reported here support the idea that differences in cognitive abilities are largely dependent on variation in (R - L) skill. This supports Annett's (1985, 1991) speculation of right shift theory and balanced polymorphism with heterozygote advantage. The problems which were there in the previous studies are now acknowledged and are being overcome. Moreover, recognised shortcomings seems to be more a thing of satisfaction than of despair. We must continue researching with a more controlled and advanced methodology. Prediction about which abilities should show linear trends (positive or negative) or quadratic trends with increasing bias to dextrality will become clearer as the hypothesis of a balanced polymorphism with heterozygote advantage (BP + HA) is further developed. In the same way that the implications of Annett's right shift analysis of 1972 had been explored step by step, so the implications of the idea of a BP + HA have to be explored in stages. Annett has made no claims to have worked out a complete model of relations between handedness, cerebral dominance and all human cognitive functions. Thus whether improbable or not, the hypothesis of a balanced polymorphism with heterozygote advantage (BP + HA) has led to several fruitful discoveries. This is the real test of a useful theory.
By and large it can be concluded that after empirical evaluation, the position of Annett is stronger than her critiques. However, present findings at the same time reveal selective gaps in accepting Annett's model. It is due to certain aspects of cognitive abilities where the expression of right-shift (rs gene) and phenotypic abilities do not correspond. Over it, the trend is also less finer. Weak dextrals seem to be at advantage but as the dextrality increases the shape and the slope of the curve is erratic, sometimes adhering to linear decreamental, other times quadratic and even both i.e. less differentiated.

Another aspect which is recently and intensively being investigated is a guess for linkage between rs + genes having their locations on sex chromosomes (Crow, 1995,1998) owing to disproportionate frequencies of females among strong dextrals. In the present study, though the occurrence was accordingly but its representation in other abilities could not be materialized. Virtually interaction of sex and handedness was thoroughly non-significant. At the same time Annett & her co-workers have also demonstrated that in case of visuo-spatial functioning the rs + gene is costly as sinistrals out perform dextrals and in case of mental rotation handedness negatively worked (Annett, 1992).

One of the reason that weight of evidence in support of Annett's model might be due to well organized representation of verbal and numerical reasoning in educational curricula as well as ability tests. It may be due to this that intellectual and academic performance seem to be better among weak dextrals. Further, weak dextrals are less lateralized in their cerebral asymmetry. It is an acceptable finding that mode of processing
differs in left and right hemispheres. Left-hemispheric dominant subjects use semantic and syntactic processing whereas right hemispheric dominant use Gestalt like and surface processing. Therefore, weak dextrals use varied and enriched processing strategies than strong dextrals or sinistrals.

In summary, present results are quite positive with respect to heterozygotic advantage hypothesis. They are consistent with the findings of Annett and her co-workers (1985, 1990, 1995). Corballis (1991), Natsopoulos et.al. (1992, 1998) and Palmer & Corballis (1996) who supported this hypothesis. There are at least three possible reasons for such a finding. First, it is possible that hypothetical genotypes of the right-shift theory exist. Second, these hypothetical genotypes have relevance for cognitive abilities. It is true that within the context of the right-shift theory there must be a reason for the persistence of the recessive allele, and it can be believed that this reason is cognitive fitness. Finally, the methods currently available for indexing the genotypes are valid and sensitive.