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PARENT-OFFSPRING CORRELATIONS UNDER HALF-SIB-MATING SYSTEM SEX-LINKED GENE CASE (GENETIC CORRELATIONS)

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SUMMARY

A study of parent offspring correlations under half-sib mating in the sex-linked gene case has been undertaken in this investigation. Three types of parent-offspring correlations viz. (i) mother-daughter, (ii) mother-son and (iii) father-daughter have been studied. A generalisation of the above three types of parent-offspring correlation have been attempted, by taking one parent and K offspring in each of these three cases. The correlation coefficients for ten generations of half-sib mating 1 to 10 offspring for each of the three cases have been worked out. It is found that these correlations increase with the increase in the number of generations as well as the number of offsprings. Further, the correlation coefficients between a mother and K sons is found to be of higher order than that of mother-K daughter correlations. In the case of a sex-linked character as the son receives his father's Y chromosome, the genetic constitution of the son with regard to that character solely depends on the constitution of his mother. This is true with every generation of half-sib mating and hence the correlation between the father and K sons will be zero at every generation of half-sib mating.

Keywords : Half-sib mating system; Parent offspring correlations; Generation matrix; Product moment correlation coefficient; Genetic effect.

Introduction

The problem of genetic correlations between relations in the case of sex-linked character has been studied by several authors such as Fisher [1], Haldane [5], Li [7], Korde [6], George [2], [3], George and Narain [4]. Fisher, Haldane and Li gave only a general treatment of the subject, whereas Korde and George made use of the generations matrix technique in studying the inbreeding systems. But in the sex-linked gene case half-sib mating system has not been touched so far. In the present investigation the parent-offspring correlations under half-sib mating system in the case of sex linked gene has been undertaken. The present study also includes a study of the correlations between one parent and K offspring under the different generations of half-sib mating systems, in the case of a sex linked character as a generalisation of one parent one offspring case.

2. Parent Offspring Correlations—One Parent One Offspring Case Under-Half-Sib Mating, Sex-Linked Gene Case.

In the present investigation the parent offspring correlation under half-sib mating—sex-linked gene case has been investigated through the generation matrix approach—studying the joint distribution of the various parent offspring pairs under different generations of half-sib mating. The different parent offspring correlations studied are

(i) Mother-daughter correlations
(ii) Mother-son correlations
(iii) Father-daughter correlations.

2.i. Mother-Daughter Correlations

Consider the case of a single locus with two allies say, "A" and "a" with frequency p and q respectively. Let the homogametic type be females and the hetrogametic type be males. Now there will be six mating types, viz. : $AA \times A$, $AA \times a$, $Aa \times A$, $Aa \times a$, $aa \times A$ and $aa \times a$. The vector of frequencies of these six types of mating can be obtained for different generations of half-sib mating as explained below :

Consider a single locus with two alleles A and a with proportion p and q, respectively. Then it may be verified that the populations

$$\begin{pmatrix} A & a \\ p & q \end{pmatrix} \text{ and } \begin{pmatrix} AA & Aa & aa \\ p^2 & 2pq & q^2 \end{pmatrix} \quad \text{are in equilibrium.}$$

under panmixia. Thus in a random mating population the constitution of the male can be A or a. Let the male be A. Now the proportion of half-sibs after random mating can be obtained by considering the mating between $A(p)$ and each of the females $AA(p^2)$, $Aa(2pq)$ and $aa(q^2)$ in population as

$$A[p^2AA + 2pqAa + q^2aa] = 1/2(paA) + 1/2(qAa) + 1/2(pA) + 1/2(qA)$$

Let the male be a, then the proportion of half-sibs corresponding to the male '*a*' can be obtained as

$$a[p^2AA + 2pqAa + q^2aa] = 1/2(pAa) + 1/2(qaa) + 1/2(pA) + 1/2(qa)$$

Combining the above two cases, we get, the proportion of half sibs for the different constitutions of the male as given in Table 1.

TABLE 1—HALF-SIBS

		AA	*Aa*	*aa*	*A*	*a*
Males	*A* (*p*)	1/2(*p*)	1/2(*q*)	0	1/2(*p*)	1/2(*q*)
	a (*q*)	0	1/2(*p*)	1/2(*q*)	1/2(*p*)	1/2(*q*)

Now consider all the brother sister pairs under each male, we get the table of proportion of brother-sister pairs under each male as in Table 2.

TABLE 2—BROTHER-SISTER PAIRS

		(*A*, *AA*)	(*A*, *Aa*)	(*A*, *aa*)	(*a*, *AA*)	(*a*, *Aa*)	(*a*, *aa*)
Male	*A* (*p*)	1/4(*p*)	1/4(*pq*)	0	1/4(*pq*)	1/4(q^2)	0
	A (*q*)	0	1/4(p^2)	1/4(*pq*)	0	1/4(*pq*)	1/4(q^2)

Hence the joint distribution of brother-sister pairs under random mating can be obtained by pooling the corresponding pairs by weighting with *p* and *q* respectively and standardising it, so that the column total as well as the row totals add up to unity, is as given in Table-3.

TABLE 3—STANDARDISED CORRELATION TABLE OF BROTHER-SISTER PAIRS UNDER RANDOM MATING

		Sister			
		AA	*Aa*	*aa*	*Total*
Brother	*A*	p^3	$2p^2q$	pq^2	*p*
	a	p^2q	$2pq^2$	q^3	*q*
Total		p^2	$2pq$	q^2	1

Similarly the brother sister pairs under the first generation of half-sib mating can be obtained as follows. There are two lines in this case—Line (i) corresponding to the male A with proportion p and with the geno-typic array of half-sib as $1/2(pAA) + 1/2(qAA) + 1/2(pA) + 1/2(qa)$ and line (ii) corresponding to the male 'a' with proportion 'q' and with the geno-typic array of half-sib $1/2(pAa) + 1/2(qaa) + 1/2(pA) + 1/2(qa)$.

The procedure consists of finding a two-way table of the frequencies of brother sister pairs corresponding to each line and then pooling these table by weighting with p and q respectively to the proportion by the different lines, to get the correlation table of brother-sister pairs under the first generation of half-sib mating as given in Table-4.

TABLE 4—STANDARDISED CORRELATION TABLE OF BROTHER-SISTER PAIRS UNDER THE FIRST GENERATION BY HALF-SIB MATING

		Sister			
		AA	Aa	aa	*Total*
Brother	A	$(1/4)\ p^2\ (1 + 3p)$	$(1/4)\ pq\ (1 + 6p)$	$(1/4)\ pq^2$	p
	a	$(1/4)\ p^2q$	$(1/4)\ pq\ (1 + 6q)$	$(1/4)\ q^2\ (1 + 3q)$	q
Total		p^2	$2pq$	q^2	1

Similarly the correlation tables of brother-sister pairs under the different generations of half-sib mating can be obtained.

Let $\underline{V}^{(0)}, \underline{V}^{(1)}, \underline{V}^{(2)}, \underline{V}^{(3)}$ be frequencies of half-sib mating types (brother-sister pairs) in the first, second and third generations of half-sib mating written from the correlation tables as explained above are,

$$\underline{V}^{(0)} = \begin{bmatrix} p^3 \\ p^2q \\ 2p^2q \\ 2pq^2 \\ pq^2 \\ q^3 \end{bmatrix} \quad \underline{V}^{(1)} = \begin{bmatrix} (1/4)\ p^2\ (1 + 3p) \\ (1/4)\ p^2q \\ (1/4)\ pq\ (1 + 6p) \\ (1/4)\ pq\ (1 + 6q) \\ (1/4)\ pq^2 \\ (1/4)\ q^2\ (1 + 3q) \end{bmatrix}$$

$$\underline{V}^{(2)} = \begin{bmatrix} (1/32)\ p\ (1 + 15p + 16p^2) \\ (1/32)\ pq\ (3 + 16p) \\ (1/8)\ pq\ (3 + 8p) \\ (1/8)\ pq\ (3 + 8q) \\ (1/32)\ pq\ (3 + 16q) \\ (1/32)\ q\ (1 + 15q + 16q^2) \end{bmatrix}$$

$$\underline{V}^{(0)} = \begin{bmatrix} (1/256)\, p\,(21 + 149p + 86p^2) \\ (1/256)\, pq\,(35 + 86p) \\ (1/128)\, pq\,(57 + 86p) \\ (1/128)\, pq\,(57 + 86q) \\ (1/256)\, pq\,(35 + 86q) \\ (1/256)\, q\,(21 + 149q + 86q^2) \end{bmatrix}$$

The column vectors $\underline{V}^{(1)}_{M-D}$, $\underline{V}^{(2)}_{M-D}$, $\underline{V}^{(3)}_{M-D}$ and $\underline{V}^{(4)}_{M-D}$ of the joint distribution of mother-daughter pairs in the first, second, third and fourth generations of half-sib mating can be obtained as

$$\left.\begin{aligned} \underline{V}^{(1)}_{M-D} &= A_{M-D}\underline{V}^{(0)}, \quad \underline{V}^{(2)}_{M-D} = A_{M-D}\underline{V}^{(1)} \\ \underline{V}^{(3)}_{M-D} &= \underset{\sim}{A}_{M-D}\underline{V}^{(2)}, \quad \underline{V}^{(4)}_{M-D} = \underset{\sim}{A}_{M-D}\underline{V}^{(3)} \end{aligned}\right\} \qquad (1)$$

where, $\underset{\sim}{A}_{M-D}$ is the generation matrix of mother-daughter pairs derived by George (3) as

$$\underset{\sim}{A}_{M-D} = \begin{bmatrix} 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/2 & 0 & 0 & 0 \\ 0 & 0 & 1/2 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}.$$

The correlation coefficients of mother-daughter pairs in the first, second, third and fourth generations of half-sib mating can be calculated directly from the correlation table formed from $\underline{V}^{(1)}_{M-D}$, $\underline{V}^{(2)}_{M-D}$, $\underline{V}^{(3)}_{M-D}$ and $\underline{V}^{(4)}_{M-D}$ respectively as

$$\text{H.S } r^{(1)}_{M-D} = 0.500; \quad \text{H.S } r^{(2)}_{M-D} = 0.587;$$

$$\text{H.S } r^{(3)}_{M-D} = 0.667 \text{ and H.S } r^{(4)}_{M-D} = 0.725$$

In general $\underline{V}^{(n)}_{M-D}\, \underset{\sim}{A}_{M-D}\underline{V}^{(n-1)}$ and the correlation coefficient, H.S $r^{(n)}_{M-D}$, of mother-daughter pairs in the nth generation of half-sib mating can be directly obtained from the correlation table formed from $V^{(n)}_{M-D}$

The correlation coefficient $H.Sr^{(n)}_{M-S}$ $(1, K)$, between one parent (mother) and K offspring (daughters) in the nth generation of half-sib mating can be calculated by using the product moment correlation coefficient formula in the line of George and Narain (4) by calculating Σfx, Σfx^2, Σfy, Σfy^2 and Σfxy as

$$\left.\begin{aligned}
\Sigma fx &= 2(V^{(n)}_{21} + V^{(n)}_{20} + V^{(n)}_{11} + V^{(n)}_{10}) \\
\Sigma fx^2 &= 4(V^{(n)}_{21} + V^{(n)}_{20} + V^{(n)}_{11} + V^{(n)}_{10}) \\
\Sigma fy &= 2KV^{(n)}_{21} + K\,V^{(n)}_{20} + 3/2\;KV^{(n)}_{11} + K/2\;V^{(n)}_{10} \\
&\qquad + K\,V^{(n)}_{01} \\
\Sigma fy^2 &= 4K^2V^{(n)}_{21} + K^2V^{(n)}_{20} + 1/4K(9K+1)\;V^{(n)}_{11} \\
&\qquad + 1/4K(K+1)\;V^{(n)}_{10} + K^2V^{(n)}_{01} \\
\Sigma fxy &= 4KV^{(n)}_{21} + 2KV^{(n)}_{20} + 3/2KV^{(n)}_{11} + K/2V^{(n)}_{10}
\end{aligned}\right\} \quad (2)$$

From these the variance of x, variance of y and the covariance of x and y can be worked out and then the correlation coefficients between the scores, x and y of the mother and K offspring can be calculated.

Now substituting $V^{(n)}$, $(n = 0, 1, 2, 3)$ values as given in (1) in relation (2), the correlation coefficient between the mother and K daughters in the first four generations of half-sib mating can be obtained as

$$H.S\,r^{(1)}_{M-D}\,(1, K) = \frac{\sqrt{K}}{\sqrt{1+3K}};\quad H.S r^{(2)}_{M-D}(1, K) = \frac{5\sqrt{K}}{2\sqrt{2}\,(2+7K)}$$

$$H.S\,r^{(3)}_{M-D}\,(1, K) = \frac{25\sqrt{K}}{2\sqrt{9\,(7+32K)}};\quad H.S\,r^{(4)}_{M-D}\,(1, K) = \frac{117\sqrt{K}}{2\sqrt{39(25+142K)}}$$

In the similar manner H.S. $r^{(n)}_{M-D}\,(i, K)$, for $n = 6, 7, 8, 9, 10$ etc. can be calculated. The correlation between the mother and K daughters in ten generations of half-sib mating when $K = 1$ to 10 are calculated and is as in Table 5.

TABLE 5—CORRELATION COEFFICIENTS BETWEEN THE MOTHER AND K DAUGHTERS IN TEN GENERATIONS OF HALF-SIB MATING, WHEN K = 1 TO 10

[No. of offspring (K)]	Generations									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.500	0.589	0.667	0.725	0.770	0.805	0.834	0.858	0.878	0.894
2	0.534	0.625	0.699	0.754	0.795	0.828	0.854	0.875	0.893	0.907
3	0.548	0.638	0.711	0.764	0.804	0.836	0.861	0.881	0.898	0.912
4	0.548	0.646	0.717	0.769	0.809	0.840	0.864	0.884	0.901	0.914
5	0.559	0.650	0.721	0.773	0.812	0.842	0.867	0.886	0.902	0.916
6	0.562	0.653	0.724	0.775	0.814	0.844	0.868	0.887	0.903	0.917
7	0.564	0.665	0.725	0.776	0.815	0.845	0.869	0.888	0.904	0.919
8	0.566	0.657	0.727	0.778	0.816	0.846	0.870	0.889	0.905	0.918
9	0.570	0.658	0.728	0.779	0.817	0.867	0.870	0.890	0.905	0.918
10	0.568	0.659	0.729	0.779	0.818	0.876	0.871	0.890	0.906	0.919

2.2. *Mother-Son Correlations*

The generation matrix $\underset{\sim}{A}_{m-s}$ of mother-son pairs as obtained by George (3) as,

$$\underset{\sim}{A}_{m-s} = \begin{bmatrix} 1 & 1 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/2 & 1/2 & 0 & 0 \\ 0 & 0 & 1/2 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 1 & 1 \end{bmatrix}$$

Thus the column vector, $\underline{V}^{(n)}_{M-S}$ of the joint frequency distribution of mother-son pairs in the nth generation of half-sib mating can be obtained from the relation

$$\underline{V}^{(n)}_{m-s} = \underset{\sim}{A}_{m-s}\, \underline{V}^{(n-1)}$$

The correlation coefficient H.S. $r^{(n)}_{m-s}$, of mother-son pairs in the nth generation of half-sib mating can be directly calculated from the correlation table formed from $\underline{V}^{(n)}_{m-s}$, by assuming additive genic effects and using the product moment formula for correlation coefficients.

The correlation coefficient, H.S $r^{(n)}_{m-s}(1, k)$ between one parent (the mother) and K offspring (the sons) in the nth generation of half-sib mating can be calculated in the similar way by calculating Σfx, Σfx^2, Σfy, Σfy^2 and Σfxy as

$$\left.\begin{aligned} \Sigma fx &= 2(V^{(n)}_{21} + V^{(n)}_{20} + V^{(n)}_{11} + V^{(n)}_{10}) \\ \Sigma fx^2 &= 4(V^{(n)}_{21} + V^{(n)}_{20} + V^{(n)}_{11} + V^{(n)}_{10}) \\ \Sigma fy &= K(V^{(n)}_{21} + V^{(n)}_{20}) + 1/2K(V^{(n)}_{11} + V^{(n)}_{10}) \\ \Sigma fy^2 &= K^2(V^{(n)}_{21} + V^{(n)}_{20}) + 1/2\,K(K+1)V^{(n)}_{11} + V^{(n)}_{10} \\ \Sigma fxy &= 2K(V^{(n)}_{21} + V^{(n)}_{20}) + 1/2(V^{(n)}_{11} + V^{(n)}_{10}) \end{aligned}\right\} \quad (3)$$

Now substituting $V^{(n)}$, ($n = 0, 1, 2, 3$) values as given in (1) in relation (3), the correlation coefficient between the mother and K sons in the first four generations of half-sib mating can be obtained as

$$\text{H.S } r^{(1)}_{M-S}(1, K) = \frac{1}{\sqrt{1 + 1/K}};\ \text{H.S } r^{(2)}_{M-S}(1, K) = \frac{1}{\sqrt{1 + 1/K}}$$

$$\text{H.S } r^{(3)}_{M-S}(1, K) = \frac{1}{\sqrt{1 + 7/9K}};\ \text{H.S } r^{(4)}_{M-S}(1, K) = \frac{1}{\sqrt{1 + 25/38K}}$$

Proceeding similarly, H.S $r^{(n)}_{m-s}$ (1, k), for n = 5, 6, 7, 8, 9 and 10 etc. can be calculated.

The correlation between the mother and K sons in ten generations of half-sib mating, when K = 1 to 10 and being calculated is as given in Table 6.

2.3. *Father-Daughter Correlations*

The generation matrix, $\underset{\sim}{A}_{F-D}$, of father-daughter pairs is derived by George (3) as

$$\underset{\sim}{A}_{F-D} = \begin{bmatrix} 1 & 0 & 1/2 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1/2 & 0 & 1 & 0 \\ 0 & 1 & 0 & 1/2 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1/2 & 0 & 1 \end{bmatrix}$$

The column vector, $\underset{\sim}{V}^{(n)}_{F-D}$, of joint distributions of father-daughter in the nth generation of half-sib mating be obtained as,

$$\underset{\sim}{V}^{(n)}_{F-D} = \underset{\sim}{A}_{F-D}\, V^{(n-1)}$$

Hence the correlation coefficient H.S $r^{(n)}_{F-D}$ of father-daughter pairs in the nth generation of half-sib mating can be directly calculated from the correlation table formed from $\underset{\sim}{V}^{(n)}_{F-D}$, using the product correlation coefficient formula.

The correlation coefficient H.S $r^{(n)}_{F-D}(1, K)$ between one parent (father) and K offspring (the daughters) in the nth generation of half-sib mating can be obtained by calculating Σfx, Σfx^2, Σfy, Σfy^2 and Σfxy

$$\left.\begin{aligned} \Sigma fx &= \Sigma fx^2 = V^{(n)}_{21} + V^{(n)}_{11} + V^{(n)}_{01} \\ \Sigma fy &= 2K\, V^{(n)}_{21} + KV^{(n)}_{20} + 3/2\, K\, V^{(n)}_{11} + K/2 V^{(n)}_{10} + K\, V^{(n)}_{01} \\ \Sigma fy^2 &= 4K^2 V^{(n)}_{21} + K^2 V^{(n)}_{20} + K/4\,(9K + 1)\, V^{(n)}_{11} \\ &\quad + K/4\,(K + 1)\, V^{(n)}_{10} + K^2\, V^{(n)}_{01} \\ \Sigma fxy &= 2K\, V^{(n)}_{21} + 3/2\, KV^{(n)}_{11} + KV^{(n)}_{01} \end{aligned}\right\} (4)$$

TABLE 6—CORRELATION COEFFICIENTS BETWEEN THE MOTHER AND K SONS IN TEN GENERATIONS OF HALF-SIB MATING, WHEN K = 1 TO 10

[*No. of offspring* (K)]	*Generation*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.707	0.707	0.750	0.781	0.808	0.831	0.851	0.869	0.884	0.897
2	0.817	0.817	0.849	0.870	0.889	0.904	0.917	0.927	0.937	0.945
3	0.866	0.866	0.891	0.908	0.922	0.933	0.942	0.950	0.956	0.962
4	0.894	0.894	0.915	0.928	0.939	0.948	0.956	0.962	0.967	0.971
5	0.913	0.913	0.93	0.940	0.951	0.958	0.964	0.969	0 973	0.977
6	0.926	0.926	0.941	0.951	0.958	0.965	0.970	0.974	0.978	0.981
7	0.935	0.935	0.949	0.957	0.964	0.969	0.974	0.978	0.981	0.983
8	0.943	0.943	0.955	0.962	0.968	0.973	0.977	0.980	0.983	0.985
9	0.949	0.949	0.959	0.966	0.972	0.976	0.980	0.982	0.985	0.987
10	0.954	0.954	0.963	0.969	0.974	0.978	0.982	0.984	0.986	0.988

TABLE 7—CORRELATION COEFFICIENTS BETWEEN THE MOTHER AND K DAUGHTERS IN TEN GENERATIONS OF HALF-SIB MATING, WHEN $K = 1$ TO 10

[*No. of offspring* (K)]	*Generation*									
	1	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*	*10*
1	0.707	0.750	0.731	0.808	0.831	0.851	0.869	0.884	0.897	0.909
2	0.756	0.796	0.818	0.840	0.858	0.875	0.889	0.902	0.913	0.923
3	0.779	0.813	0.832	0.851	0.868	0.883	0.896	0.908	0.919	0.928
4	0.784	0.822	0.839	0.857	0.873	0.887	0.900	0.911	0.921	0.930
5	0.791	0.827	0.844	0.861	0.876	0.890	0.902	0.913	0.923	0.931
6	0.795	0.831	0.847	0.863	0.878	0.892	0.904	0.914	0.924	0.932
7	0.798	0.834	0.849	0.865	0.880	0.893	0.905	0.915	0.925	0.933
8	0.800	0.836	0.850	0.867	0.881	0.894	0.906	0.916	0.925	0.934
9	0.802	0.837	0.852	0.868	0.882	0.895	0.906	0.917	0.926	0.934
10	0.803	0.839	0.853	0.868	0.883	0.895	0.907	0.917	0.926	0.934

Substituting the $V^{(n)}$ values, for $n = 0, 1, 2, 3$ the correlation coefficients can be worked out as follows :

$$\text{H.S } r^{(1)}_{F-D}(1, K) = \frac{2\sqrt{K}}{\sqrt{2(1+3K)}}; \text{ H.S } r^{(2)}_{F-D}(1, K) = \frac{2\sqrt{K}}{4\sqrt{2+7K}}$$

$$\text{H.S } r^{(3)}_{F-D}(1, K) = \frac{39\sqrt{K}}{8\sqrt{7+32K}}; \text{ H.S } r^{(4)}_{F-D}(1, K) = \frac{167\sqrt{K}}{16\sqrt{25+142K}}$$

Proceeding in the same line we can find H.S. $r^{(n)}_{F-D}$ (1, K), $n = 5, 6, 7, 8, 9, 10$ etc. can be calculated.

The correlation coefficients between the father and K daughters in ten generations of half-sib mating when $K = 1$ to 10 are being calculated and is given in Table 7.

3. Conclusions

It is observed that correlations increase with the increase in the number of generations as well as the number of offsprings. The correlations between a mother and K sons is found to be of higher order than that of mother-K daughter correlations. In the case of a sex-linked character as the son receives his father's Y chromosome, the genetic constitution of the son with regard to that character solely depends on the constitution of his mother. This is true with every generation of half-sib mating and hence the correlation between the father and K sons will be zero at every generation of half-sib mating.

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