cially significant during autumnal mass migrations. Because queuing behavior during mass migration is thus far known only in *P. argus*, it seems that this species was subject to some selective pressures different from its congeners, which was directed toward increasing locomotor efficiency (*10*). Other, less easily measured phenomena may serve similar functions in formation movements of other aquatic, terrestrial, and aerial species. While continuing to investigate both the hydrodynamic mechanism and the evolutionary significance of queuing, we suggest that it potentially serves other important biological functions, for example, in defense against predation and for group orientation. However, such functions are considerably more difficult to examine experimentally.

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11. We thank N. Schuh and R. Ball of the Naval Coastal Systems Laboratory, Panama City, Florida, for technical assistance; and W. Tschinkel, P. Hamilton, and R. Krishnamurti of Florida State University for a critique of the manuscript. The work was funded by grants to W.F.H. from Florida State University and the National Science Foundation (BMS 74–22276). We appreciate the continued support of the Psychobiology Program at Florida State University.

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Handedness in a Chinese Population: Biological, Social, and Pathological Factors

Abstract. *A questionnaire survey of 4143 Chinese was conducted. Social pressure for right-handed writing and eating was effective on these two target skills but showed little indirect influence on hand use in other activities. Neither primiparous birth nor birth to older mothers affected handedness. Twinning, however, seemed to be associated with both decreased right-handedness and lower intelligence.*

It is commonly acknowledged that human handedness is genetically predisposed, but its expression can be modified by either social pressure or brain damage (*1*). The extent of social influence on handedness has not been studied directly and cannot be examined readily in most present-day Western societies because of the current tolerant attitude toward left-handedness. Primiparous birth, birth to older mothers, and twinning have been proposed as circumstances that may result in brain damage and consequent altered handedness, but the results have been inconsistent (*2*).

We conducted a questionnaire survey on handedness in a Chinese population in Taiwan, where social pressure for right-handed writing and eating is still strong. One of our purposes was to examine the extent to which social influence affects hand use in these two "target" skills, as well as in ten other activities of little social concern. The relations between handedness and each of the three high-risk birth conditions mentioned above were also studied. Social pressure was found to be highly effective in changing hand use in the target skills, yet it showed little transfer effect on hand use in other activities. Handedness was found to be totally unrelated to either primiparous birth or birth to older mothers. Conversely, twinning seemed to be associated with both decreased right-handedness and lower intelligence.

Our sample consisted of 1048 boys and 1054 girls arbitrarily drawn from 4th- and 5th-grade classes, plus 1025 male and 1016 female students sampled from various departments in several prestigious universities. Taiwan has 9 years of public education; however, college entrance there requires passing very competitive entrance examinations. The acceptance rate is only about 3 percent of the applicants in the universities sampled. Thus the elementary school sample can be considered to be a fair representation of the general population, whereas the college sample is highly selected for academic intelligence.

The questionnaire is similar to the one used in Oldfield's Edinburgh study (*3*). It asks about the hand used in the following 12 activities: unscrewing a jar lid, opening a door, striking a match, hammering a nail, brushing teeth, erasing a blackboard, cutting with scissors, throwing a ball, raising the hand (before asking questions in class), reaching into a jar, eating (with chopsticks), and writing. For each activity, the subject was to put two crosses under either "Right" or "Left" if he habitually used the corresponding hand for it. He was to put one cross each under "Right" and "Left" if he used the two hands interchangeably. The same questionnaire also asked about birth order, twin birth, and whether or not the respondent had experienced frequent remindings or requests to change hand use from the left to the right during early childhood.

Our main analyses about social and neuropathological factors in handedness are given below. Results from the elementary school and the college samples are combined in our discussion except where a significant difference has been found between them. Results from the two sexes are similarly combined.

Of the 4143 subjects, 18 percent reported having experienced frequent requests to change hand use from the left to the right. A scanty 0.7 percent of the subjects still used the left hand for writing, and 1.5 percent still used the left hand for eating. Since only individuals who have a natural tendency for left-handedness or

mixed handedness are expected to experience social pressure for hand change, these statistics demonstrate the prevalence of social interference, as well as its effectiveness on these two target skills. As a comparison, a recent study in Berkeley, California, showed that 9.9 percent of 7146 non-Oriental schoolchildren and 6.5 percent of 538 Oriental schoolchildren used the left hand in writing (*4*).

Conversely, successful conversion to right-handed writing or eating does not seem to have substantially affected hand use in other activities. A "laterality quotient" or LQ (*3*) was calculated for each subject, on the basis of his responses to the ten activities other than writing and eating, as an approximate measure of his natural-handedness. The LQ was derived by subtracting the number of crosses under "Left" from that under "Right," dividing the difference by the total number of crosses, and multiplying the resulting fraction by 100. Thus LQ = 100 indicates exclusive right-handedness, LQ = −100 indicates exclusive left-handedness, and the closer the LQ value is to zero, the less is a lateralized manual preference. The distribution of the LQ values for natural handedness, aside from the socially influenced hand use in writing and eating, covered the whole range of possible lateral preferences (Fig. 1) and was similar to the distributions obtained in Western samples (*3, 5*), including the finding of more left-handed cases among male subjects. Actually, the two sexes have the same mean LQ of 65, but males showed a larger variability (S.D. = 37) than females (S.D. = 31). As a more direct indication of the limited transfer effect of social molding on the nontarget activities, subjects who had received frequent requests to change hand use still used their right hand, on the average, significantly ($z = 12.70$, $P < .001$) less frequently (mean LQ = 45, S.D. = 50) than those who had not (mean LQ = 69; S.D. = 28). The larger standard deviation in LQ values found in the former group agreed with the general observation, on the basis of Western samples, that the left-handers are a more heterogeneous group than the right-handers (*6*).

The limited conversion effect shown above demonstrates a certain degree of tenacity of the biological predilection involved in handedness. It also raises interesting questions with regard to the cerebral loci and pathways involved in manual skills. Our findings indicate that a naturally left-handed individual can be successfully trained from early childhood to use his right hand for eating and writing; yet he may continue to prefer his left hand for other skilled activities, such as cutting with scissors. In such cases, is a separate center for fine motor control established in the opposite hemisphere, or is an ipsilateral pathway established only for the socially censured activities? The possibility of separate cerebral centers or pathways for different kinds of skilled manual activities is raised.

Table 1. Handedness (LQ) in relation to twin births.

Sample	Twin birth	Cases (No.)	LQ	
			Mean	S.D.
Elementary	Yes	44	50	59
	No	2058	66	34
College	Yes	18	66	36
	No	2023	64	34

Several studies have examined the association between handedness and birth order on the basis of the following reasoning. Subtle brain damage in the dominant left hemisphere may cause a change in handedness from the right to the left. Firstborns and children born fourth and later are relatively high-risk cases because the firstborn child is typically associated with longer labor and often with the use of instruments, while children born fourth or later tend to be associated with older mothers. Although increased left-handedness is expected in this high-risk group, findings have been inconsistent (*2*). However, several shortcomings in the methods used in these studies may have precluded a sensitive resolution of the relation involved. (i) Only university students were examined, which might have excluded a large proportion of individuals with subtle or frank neuropathology. (ii) Only the writing hand was used for handedness classification, which thereby lacked graded differentiation. (iii) The firstborns and the children born fourth and later were combined in a single high-risk group, in contrast to a low-risk group of children born second and third. It is reasonable to suspect that the difference in mothers' ages between the two groups was not large enough for the detection of a possible association between left-handedness and older mothers.

We have calculated the mean LQ value for each birth order in our elementary school sample of 2102 pupils. Their birth order ranged from one to nine. The nine mean LQ values varied little (from 63 to 68), and the differences were not significant ($F < 1$). Both the firstborns ($N = 534$) and the group of children born ninth ($N = 21$) had a mean LQ of 68. Therefore, not even a supportive trend was obtained. This result provides strong evidence against regarding primiparous births and births from older mothers as being associated with pathological left-handedness.

Conversely, our data did indicate an

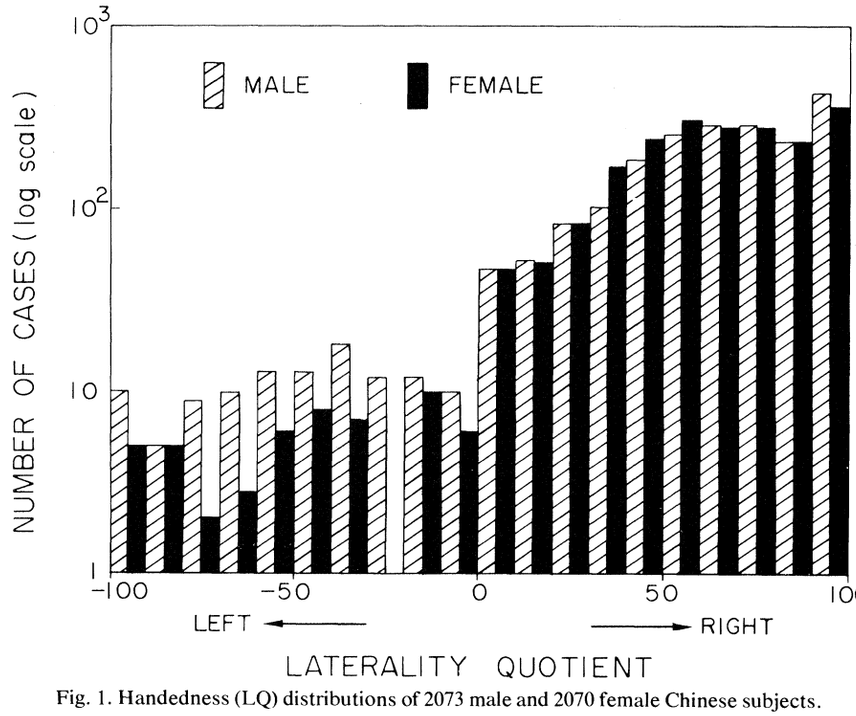

Fig. 1. Handedness (LQ) distributions of 2073 male and 2070 female Chinese subjects.

association of twinning with both decreased right-handedness and reduced college entrance (Table 1). In the elementary school sample, twin-birth subjects had a mean LQ that was 16 points lower than that of single-birth subjects ($z = 1.79$, $P < .05$, one-tailed test). A higher incidence of left-handedness among both monozygotic and dizygotic twins has also been found in Western studies (*7, 8*). Furthermore, one study located eight pairs of twins with discordant handedness of which one member was institutionalized for mental retardation and the other was not. In all cases, it was the left-handed member who was institutionalized (*8*). Although we found comparable handedness between twin-birth and single-birth subjects in our college sample, it is important to note that the percentage of twin-birth subjects in the college sample was less than half of that in the elementary school sample (chi square = 10.31, $P < .01$). Since subjects in our college sample were highly selected for academic successes, the pattern of results supports the earlier Western findings in indicating that twinning may sometimes affect both handedness and intelligence. The relatively high risk status of twinning during both prenatal and perinatal periods is well known (*9*). Among a variety of possible factors, such as intrauterine crowding, long labor, and low birth weight, which may be particularly responsible for possible cerebral impairment, remain to be determined.

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Malaria: Successful Immunization Against the Sexual Stages of *Plasmodium gallinaceum*

Abstract. *Gametocyte infectivity and oocyst development of the avian malaria parasite,* Plasmodium gallinaceum, *can be reduced or eliminated in mosquitoes by immunizing the chickens on which the mosquitoes feed with infected red blood cells that have been treated with formalin or x-rays. Protection of the mosquito appears to be related to the immobilization of the microgametes in its gut and is associated with the immunoglobulin G fraction of serum.*

Successful immunization with malarial sporozoites and merozoites (*1*) is thought to be dependent upon the vulnerability to serum factors of the invasive asexual stages of these protozoan parasites when they are outside vertebrate host cells. Malarial parasites are also exposed to the extracellular environment in another phase of development when the sexual parasites, the gametocytes, shed their erythrocyte membranes after being ingested by a mosquito. In the gut of a mosquito vector, gametocytes give rise to spermlike male gametes and nonmotile female gametes which fuse; the resulting ookinetes (zygotes) penetrate the gut epithelium to produce oocysts. It is the oocyst which ultimately produces sporozoites capable of infecting a vertebrate host to complete the cycle of transmission when the mosquito feeds again.

That host factors can interfere with the capacity of gametocytes to produce oocysts in mosquitoes has been noted (*2*), but not pursued. In this report I describe an immunity induced in chickens which affects only the sexual stages of the avian malaria parasite, *Plasmodium gallinaceum*, within the gut of the mosquito vector.

New Hampshire Red chickens were immunized with red cells infected with *P. gallinaceum* that had been inactivated by treatment with formalin (1 percent for 30 minutes; the cells were then washed twice and resuspended in saline) or with

Table 1. The effect of various immunization schedules on oocyst development on the gut of mosquitoes. Parasitized erythrocytes (2×10^9) were inactivated with formalin or x-rays and injected into chickens intravenously. The data for parasitemia are expressed as the numbers of oocysts per mosquito gut (mean of ten mosquitoes per chicken per day) when the mosquitoes fed upon chickens with parasitemias within the ranges indicated below and for decreasing (1 day after peak) parasitemia.

Number of weekly injections	No. of chickens	Parasitemia (% infected erythrocytes)*						Cumulative mean oocysts per gut for 5 days†
		≤ 0.4	0.5 to 5	6 to 40	41 to 85	Decreasing		
Formalin-treated antigen; avian host challenged with 10^5 parasites								
5	1	0	0	0	0	0		0
4	5	0	0	0.04	0.1	0.01		0.03
3	3	0	0.07	5.6	6.8	0.02		2.4
2	9	4.2	27	33	17	1.2		17
1	5	11	32	103	76	30		50
X-irradiated antigen; avian host challenged with 10^5 parasites								
4	2	0	0	0.2	0.7	0.07		0.19
3	7	0	0.4	1.9	2.7	0.3		1.1
2	5	0.08	2.9	3.9	5.5	4.5		3.4
1	1	9	58	94	41	11		43
Nonimmune control; avian host challenged with 10^5 parasites								
None	15	14	82	164	35	18		63
X-irradiated antigen; avian host challenged with bites of ten mosquitoes								
3	3	0	3.1	2.2	‡	1.7	0.2§	1.4
2	4	1.6	18	10	‡	4.4	0.2§	6.8
Nonimmune control; avian host challenged with bites of ten mosquitoes								
None	10	41	110	72	‡	77	39§	68

*Parasite count increased at a predictable rate with 3 days of increasing parasitemia prior to the peak. †Ten mosquitoes per chicken for each of 5 days of maximum oocyst production. ‡Maximum parasitemia in sporozoite-induced infections less than 40 percent. §Two days of decreasing parasitemia were recorded here.