THE INFLUENCE OF HUMAN LATERALITY
ON
THE DESIGN AND CONTROL OF VEHICLES

BY

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THIS THESIS IS SUBMITTED IN FULFILMENT OF THE DEGREE OF MASTER OF PHILOSOPHY IN THE UNIVERSITY OF SURREY.
This thesis covers research into the influence of human laterality on the evolution, design and operation of specific vehicle types.

The research covers those aspects of human evolution and behaviour which appear relevant to man in a control interface. The research into human behaviour establishes the concept of 'skewed' man and relates it to the right-hand-world of artifacts.

The research and dissertation covers: water craft; animal-hauled vehicles; steerable land vehicles; steam railway locomotives; aircraft; space and future vehicles.

For each of the transport systems studied an analysis is made of the extent of the influence of human laterality in relation to other factors; such as mechanical considerations. The research was made against the background of two principal factors: the Olympic anti-clockwise circling and the right-hand sword.

As a bridge between non-vehicular and vehicular control interfaces, some artifacts are described as quasi-vehicles; the plough and the pianoforte for example.

For each form of transport, for each type of control position and for each operating environment there are specific conclusions about the degree of the influence of human laterality.
Two general conclusions are:-

1. The longer established forms of transport usually exhibit the most evidence of the influence of laterality in the design of the control interface, whereas the more recent forms of transport show a greater influence on the rules governing the conduct of vehicles in the operating environment.

2. Increasingly the control interfaces of all types of transport tend towards less emphasis of human laterality factors as control inputs requiring muscular effort are replaced by simplified 'low-effort' tactile inputs.

Two pilot experiments are described: one with primary school children; the other with adults as subjects. The objective of the experiments being to find the extent to which experience of dextrad forms influences the arrangement of controls in a man/machine interface. These experiments are intended as recommendations for full-scale testing directed towards results which might give quantitative indications of the influence of human laterality on the design of vehicle control positions.
GENERAL INDEX TO ALL SECTIONS

INTRODUCTION. Section: Intro.

HUMAN LATERALITY. Section: One

SKewed MAN. Section: Two

CONTROL EVOLUTION, RULES OF CONDUCT AND ASSOCIATED HUMAN FACTORS FOR SPECIFIC TYPES OF VEHICLES. Section: Three

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Primary and Secondary references to sources follow Sections One and Three only.
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Appendix.
People and Organisations consulted during the research and preparation of the thesis.
As a subject, this thesis started in 1972 following twenty years of interest in ergonomics: those years saw the study of all forms of transport, although aviation, as the author's profession, dominated and provided the basic understanding of the different relationships which existed in man/machine 'M/M' control interfaces. Increasingly, as research into the evolution of control position design and use continued there arose questions about the origins of control and control position asymmetries in vehicles. Were they the result of mechanical, dynamic, chance or human preference factors? Also, what were the origins of left and right preferences in the conduct of vehicle?

The concept of the thesis was discussed with a number of authorities in the different but related disciplines of ergonomics, transport and the behavioural sciences in general. In particular the concept was actively encouraged by Dr J.M. Rolfe of the RAF Institute of Aviation Medicine, by Air Vice Marshall M.E.M. Perkins and Wing/Cmdr. E.W. Anderson of Smiths Industries Aviation Division. Also encouragement was given by C.H. Gibbs-Smith, Keeper Emeritus of the Victoria and Albert Museum, who commenced a parallel research into directionality in Art.

The author acknowledges and expresses his appreciation of the encouragement and help of the above and also of the Department of Psychology at the University of Surrey: in particular that of Professor Terence Lee and Mr Russell Wicks and of the Training Manager of the Aviation Division of Smiths Industries, Mr J. West M.Sc., and Mrs. C. Chapman who typed and proof read the manuscripts.
The main questions which were approached were:

What motivated those who conceptualised and made artifacts, particularly vehicles, to select one side in preference to the other so that there was a significant degree of bilateral asymmetry?

What could be said about the significance of bilaterally asymmetrical vehicles and man/machine interfaces in relation to the practices and rules of vehicle conduct?

How did individuals organise their conception of a control interface?

The foregoing questions generated another main question: what factors of human behaviour accounted for discernable variations in control interface topography?

Before outlining the specific areas of research it was necessary to define the scope of the investigation.

Firstly, the research was concerned primarily with qualitative rather than quantitative differences.

Secondly, the literature and other sources of data contained very little direct reference to human laterality and its effects and consequences in relation to specific vehicular systems.

Therefore, it was found necessary to research the areas of human laterality and vehicle evolution which, although they were inter-dependent within the thesis subject, had to be studied separately. Human laterality was researched from evidence of primitive societies to the present day so that an understanding was available of the behaviour of the human component of the man/machine interfaces which formed the specific examples studied in detail.
Research objectives

The primary objective of the research and the thesis was to submit conclusions which showed the extent of the influence of human hand and side preferences on the evolution of vehicle controls, control positions and the manoeuvring of vehicles.

Basic Hypothesis

The inferences which led to the basic hypothesis were based on the observations from the research which showed that human laterality may have dominated the decisions of designers and builders of vehicles and craft when arranging the controls and the control position. Handedness and lateral preferences, including traditional and ceremonial, had, in the majority of the examples studied, involved a simple choice between right and left. In other examples the choice process had to consider the requirements and the constraints of mechanical systems and the limitations of the vehicle dynamics in the operating environment.

The basic hypothesis for the thesis was as follows:

That the influence of human laterality and lateral preferences on the evolution and the design of controls and the control practices for vehicles and craft were significant factors in the majority of the specific types studied. The following subjects were embraced by the hypothesis:

- Human lateral preferences.
- Human traditions, customs and traits.
- The controls and control positions of vehicles and craft.
- Rules and customs relating to the manoeuvring of vehicles and craft in the operating environments.
Methodology

Int. 3.1 Research

The research for the thesis was based on previous studies of a number of different man/machine interfaces for land, sea and air vehicles. However, those studies had not been based on a systematic application of ergonomic reasoning and were concerned primarily with a search of the relevant literature and with the effects rather than the causes.

The research programme, during the qualifying period set by the University of Surrey, related existing man/machine interface factors to the history of the evolution of control positions and to the rules and customs for the conduct of vehicles.

The first part of the programme was concerned primarily with research into handedness in an attempt to apply applicable parts of the research literature to specific man/machine interface situations.

Part of the study of the handedness research findings was concerned with showing which of the findings were applicable directly to man-in-control situations.

The general term 'right-hand-world' was given careful consideration to ensure that it could be used as a definition with limitations clearly defined. An important part of the specific studies of human laterality was concerned with the establishment of clear definitions applicable to man/machine interfaces in general. The popular conception of the right-hand-world with a 9 to 1 predominance of right-hand-preferring people was too crude. Therefore, the findings of Mary Clark and Marion Annett were used as starting points when describing the lateral characteristics of the human component of man/machine interfaces.
The first two sections of the thesis cover: the evolution of man and his artifacts; the evidence of human lateral preferences when making and using artifacts; and modern research into human laterality. Overall, these sections endeavoured to construct the evolved behavioural characteristics of the human component of the man/machine interface.

The third section of the thesis covers the evolution of vehicles and their controls and the rules of conduct. This part of the thesis consists of parallel studies of the different forms of transport.

The fourth section gives the conclusions and makes recommendations for future research based on pilot studies (described in detail in the Appendices to section 4). A bibliography and reference list is appended to each of the main sections of the thesis.

Int. 3.2
Causes and Effects

As a generalisation it was hypothesised that because man was on earth before artifacts then human lateral characteristics were the cause and the effect was the way in which man/machine interfaces evolved having characteristics influenced by that laterality.

The foregoing was a methodology adopted to examine both the particular and the general. Each of the major man/machine interface factors were studied to establish which was cause and which was effect.

Int. 4.
The place of the thesis in technology and culture

One objective of the research was to ensure that historians of technology and culture, working in the future, would not be faced, as they sometimes are at the present time, with a sparsity of information about the evolution of artifacts. This objective was similar to that
implied by Meighan (1960) when he wrote (p.336): "Primitive technologies deserve more study than they have received" and (p.339): "... researchers, travellers etc........ have almost universally failed to record...fundamental information......"

The artifacts of the 19th and 20th centuries will one day be classified as primitive.

Meighan pointed to the lack of information concerning: the time taken to make an artifact; the range of tools available for specific purposes and the effectiveness of hunting devices. It is postulated that he might have included questions about the handedness of artifacts.

One of the specific studies which influenced the research for this thesis was Fritsch (1968) because this included some significant signposts. As an example Fritsch (p.9): "Right and Left, appearing at all levels of organisation could prove to be key concepts (in science and life) ..." and on page 137: "... should man be adapted to his tools, or the tools to the man?".

Just as the available evidence of earlier technologies and cultures gave only limited detail so does evidence, research and comment on the influence of hand and side preference in pre-history and early history give only limited information. It is postulated that the predominant influences of the right-hand and right-side preference cultures, which continually reinforced the right-hand-world of technology, have been fundamental and unvarying features which have existed for all time and in all social groups so that researchers and historians have been given little incentive to consider in detail the origins of artifacts which have been influenced by human laterality.

This thesis does not argue against the evidence of the right-hand-world, rather it attempts to explain the possible significance of steps which eventually resulted in the modern relationships of human hand and side preference in vehicle control practice.
One question which remained in the background of the research and for which an answer was not sought is: did evolution proceed from the reinforcement of innate lateral characteristics by the cultures and technologies in which man lived or were innate lateral characteristics, in the absence of the influence of an asymmetrical world of artifacts, physiologically limited?

The available evidence for this thesis was summarised and cross-referred in an attempt to define qualitatively the influence of human laterality and to provide other researchers and historians with a guide to one specific aspect of culture and technology. The physiological and behavioural aspects of man, which have been interwoven with the technological aspects of vehicles, are intended to fill some of the gaps in our knowledge concerning the evolution of man/machine interfaces and to provide pointers to future research; particularly in environmental psychology.

Int. 5
Ergonomics

Int 5.1
The applications of ergonomics and human laterality

An essential part of the research was reference to ergonomics. The following relationships between pre-ergonomics and modern studies of the man/machine interface were considered:

Research into the evolution of artifacts showed how man had adapted natural objects as tools. As artifact begat artifact each became progressively refined because man sought always an improvement in efficiency of operation. Throughout the history of the evolution of artifacts there was clear evidence of the general influence of right-hand-preference (RHP) on the design of artifacts; the form of which allowed the use of either hand.
It was noted that convenience of use was the principal 'design' factor for man's early implements from which came designs which remained unchanged until modern times. Efficiency of action and ease of use characterised many of the artifacts which remained in use for tens of thousands of years. Even with modern materials and manufacturing processes the basic relationships, which existed between handle and operating surface, had not been changed. In contrast, the man/machine interface of vehicles did not have a comparable evolutionary history because, in general, man had had to adapt to the machine.

The extent of the application of eronomics depended, in general, on the consequences of human error; with one source of error being controls not designed specifically to account for human lateral preferences. Some ergonomic relationships had come about because of human preferences and attempts by designers to relate man to the machine. Human hand-preference, with a dominant right-hand preferring population, might have influenced those relationships.

Some of the machines and vehicles studied had been long on the scene before the disciplines for studying and quantifying man/machine relationships had been established and hand preference factors per se were not generally given consideration by inventors, designers or contrivers. Overall, man's ability to adapt to his environment and circumstances disguised shortcomings in human performance and to some extent the effects of hand preference.

For each type of vehicle studied there was a simplified construct which was used to show the degree of asymmetry about the medial in the normal direction of movement and which showed any asymmetry of the vehicle's conduct relative to the medial of its track or path.* That generalised approach to the study of vehicle control included both freely-manoeuvrable

* These simplified constructs are illustrated in Int. 8.2.
as well as track-guided vehicles. Both major classifications provided examples which exhibited discernible hand- and side preference factors and design characteristics related to the rules and customs which governed their conduct about the ways. The principal track-guided type studied was the railway. The principal freely-manoeuvrable type studied was the aircraft which had contributed much to the development of the man/machine interface and to the first years of the establishment of ergonomics.

The conduct and control of vehicles required the application of disciplines in order to achieve the socially acceptable levels of safety and the required levels of economy of operation. Many of the basic disciplines to which the operators of vehicles were subjected had military origins which in turn were derived from hand- and side-preferences as modified and reinforced over long periods of time.

The traditional and magical properties of weapons, particularly the sword in the right-hand, provided a starting point for tracing the origins of much of the custom and tradition which influenced the control and conduct practices for vehicles at the start of each of the major upward steps in world technology arising from each new form of transport.
Research into handedness factors in man/machine interfaces.

The literature and reports studied contained few examples of handedness investigations in specific vehicle control interfaces. Therefore, it was considered important to investigate the possible reasons. The following reasons were considered:

(a) Adaptability of the human operator to the M/M interface was relied upon by designers and that adaptability tended to disguise the adverse effects of an interface which did not match an operator's lateral preferences; such as the need to use the non-preferred hand in a display/control (DC) stereotype.

Man's ability to adapt to his environment and circumstances tended to overcome and disguise adverse anthropotechnical situations. Only extreme dextrality appeared to have been an exception to that adaptability. It was only when the consequences of human control errors became serious that consideration was given to the possibility of improving the man/machine interface and in particular the handedness so that the operator was less likely to make mistakes.

That questions were asked about unsafe interfaces and answers sought was not disputed but what was not available from the evidence studied were records showing where the dividing line had been drawn between innate and cultural behaviour during the approach to pre-ergonomic problems and, possibly more importantly, between chance and a conceptual process in which handedness and the dextrad writing form were dominant features.

(b) The right-hand and right-side-preferring (RHP) population factor may have been an important influence on design decisions which involved making a choice between placing equipment to the right or to the left of a medial.

It was noted that in the 1970s improvements to the man/machine interface in general were becoming marginal and that the influence of hand
preference was becoming of less significance because interfaces were being introduced which did not have large wheels and levers requiring muscular effort and consideration of the preferred hand of the operator. Increasingly machines were being adapted to men but at the same time the right-hand-preferring population remained the stereotype.

Int. 6.
Summary of the principal evidence studied

The preferred right-hand in pre-history and in the 'transport' age (c 3000BC onwards)

The right-hand-world with an increasing number of artifacts from 3000BC to about 1900AD which were right-handed (RH) followed by a decreasing number of types of RH-only artifacts as control interfaces became adaptable to either hand.

The parallel histories of apes and man, with the former's absence of vocal language reflecting the general absence of handedness.

Language, handwriting and dextrad skills from 3000BC to c 1900 which were followed gradually by alternative communication methods which tended to displace the pre-eminence of handwriting; thereby modifying the influence of the right-hand-world.

Social behavioural customs in many societies and ethnic groups which prescribed 'good', 'acceptable', magical and moral strength to the right-hand and right-side and from which are derived traditional and religious movements, patterns and circlings to the right. The contrary direction factors which referred to evil, weakness, femininity etc. plus the significance of the Olympic anti-sun circling.

Dextrad tendencies in conceptual processes for art and science. Evidence, from studies of perceptual behaviour, of the dextrad conceptual and motor processes; particularly in those populations using a dextrad handwriting.
Mechanical convenience, as an influence on the design of control equipment, which deliberately or by default, overrode considerations of hand- and side-preference factors.

The factor of chance which could have been of greater significance than hand- and side-preference or mechanical convenience.

The possible influence of interpersonal behavioural factors on the design and operation of control interfaces.

The possible influence of environmental psychological factors on the design and operation of vehicles.

Int. 7

Glossary

H  Handedness factors
DC  Display/Control
M/M  The man/machine interface
RHP  Right-hand preferring/or preference
LHP  Left-hand  "  "  "
RSP  Right-side  "  "  "
LSP  Left-side  "  "  "
PH  Preferred hand
NPh  Non-preferred hand
RHW  Right-hand-world
VM  Vehicle or craft medial
OM  Operator's medial
TM  Track medial
IPB  Interpersonal behaviour
S/S  Sword/Scabbard handedness customs
'bow-anomaly' - the practice of artists depicting the bow on the side of the operator which the viewer can see irrespective of the handedness (H) of the operator.

(... K) K is used as an abbreviation for thousands.

direct DC stereotype - if a given control movement produces a pointer movement in the same direction.

reversed DC stereotype - the reverse of a 'direct' DC relationship

Pre-Ergonomic - Before about 1940.

Vehicle - General term for all types of land, sea, water and air vehicles.

Craft - General term for all types of sea, water and air vehicles.

Definitions, explanations and terminology

Vehicles

The subject title of the thesis refers to 'vehicles and craft' and the scope of research and discussion included the following:

Marine and river craft; horse and animal hauled transport;
railway locomotives and trains and other track guided transport systems; automobiles and other steerable land transport methods; aircraft and flying machines in general.

The term 'vehicle' is used in its widest sense, as in the dictionary definition: 'a means of conveyance'.

The term 'craft' is used when describing or referring to any form of waterborne vehicle.

However, when references are generally applicable to most types and forms of vehicle and craft then the term 'vehicle' is used.
Explanation of the man/machine inter-relationships considered and of the vehicle/operating environment inter-relationships

Fig. A illustrates the relationships between the following factors:

VM, the vehicle or craft medial. The majority of vehicles and craft considered in this thesis exhibit symmetrical forms about the medial line which joins the leading and the trailing extremities in the usual direction of motion when seen in plan view. There are exceptions, such as the crooked-stern junks of China and the asymmetric hulls of Venetian gondolas. Furthermore, equipment is sometimes superimposed on a basic plan which gives apparent asymmetry.

OM, the operator's medial. This is used as a reference to show the displacement of the operator, bilaterally, from the vehicle medial (VM) and as a reference for relating the operator generally to the controls and instruments of the man/machine (M/M) interface.

With the general exception of the larger types of marine craft and armoured fighting vehicles the operator, as a definition, refers to the member of the crew whose task it is to control directly, at a man/machine interface, the vehicle in its operating environment. Apart from the aforementioned special cases, in the majority of land vehicles, railway vehicles and aircraft studied, the person-in-command is also the principal operator of the primary control interface. The horseman, the coachman, the rower, punter, paddler, small-boat sailor and the sculler, the locomotive or train driver, the motorist, the lorry driver and the pilot-in-command (aircraft) sit or stand at the man/machine interface and operate directly the controls.

The exceptions, referred to above, of the larger marine craft and some fighting vehicles did not admit such a simplified operator/vehicle
construct as that normally used. In those sections of the thesis dealing with the evolution of control artifacts for ships (sect. 3.1) descriptions are given of the equipment and operating environments which made it impracticable for the person-in-command to act also as the operator of the primary controls.

Fig. Int.8.2.A shows DO, the displacement of the OM from the VM. It is a characteristic of many types of vehicles and craft than mechanical and operating convenience factors relative to the track and other vehicles have contributed to the evolution of vehicle forms having an operator's position to one side of the VM.

The DO is used only to indicate qualitatively in diagrams the extent of the operator's displacement and to which side of the VM. When describing the displacement of a vehicle from the track medial, DV is used as an abbreviation.

Fig. Int.8.2.B shows the vehicle operating environment with DV indicating, qualitatively, the displacement from the track medial. (TM).

Fig. Int.8.2.C is a simplified diagram used when showing the relationships of operator's position, vehicle relative to track and the rules and customs applicable when conducting the vehicle about its ways.
Simplified man/machine and man/vehicle interface to illustrate introductory section of thesis

Fig. Int. 8.2.A

Simplified vehicle environment/operating environment construct

Fig. Int. 8.2.B
Simplified diagram of the relationship between the operator's position, the vehicle relative to track medial and the rules and customs for conducting a vehicle in the presence of other vehicles.

Fig. Int. 8.2.C.
PEOPLE AND ORGANISATIONS WHO WERE CONSULTED DURING THE
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Department of Psychology, University of Surrey.

Trinity House.

Technical Editor, Flight International.
Section 1

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1.2. Evolution of tools and weapons

1.3. Technology in the ancient world

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<td>1.12.6 (c)</td>
<td>Operator/Audience relationships</td>
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<td>Social and Military precedence</td>
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1.1.
The evolution of handedness and side preference in pre-history.

1.1.1. Introduction.

It was found necessary in the study of the influence of human laterality on the design of vehicle controls and operation to consider innate and learnt human preferences in pre-history and particularly in the time before the development of waterborne and wheeled vehicles.

The evolution of vehicle control could have been studied using, without further research, the evidence of the majority, right-hand preferring populations and proceeding from that basis. The weakness of that procedure was that it did not consider adequately the possible influences of ambidexterity as a characteristic of the man-like apes who were able to adapt natural objects as artifacts. At the same time it was clearly desirable to establish a time in history from which to trace the evolution of artifacts which had been influenced by human laterality. Otherwise much research would have had to have been made into artifacts and cultures from earlier periods which, possibly, had little relevance to the subject of the thesis.

One of the foundations of the research was the construction of an assumed chronology of right-hand-preference (RHP) development based on the laterality characteristic of the higher apes and of pre-civilisation man, which led to the sun-worshipping religions, to the steering oar and to the 'sword' customs.

1.1.2. The possible origins of human laterality and preferences in pre-history.

Pre-historic man's brain had an intellectual capacity which was not innately different from that of modern man. However, his technical devices were often laborious, even though uncomplicated, with the result
that they provided only a limited stimulus to conceptual thought. That observation by anthropologists provided a measure for considering the relative progress of homo-sapiens and the apes. Modern studies of the behaviour of chimpanzees emphasised the limitations to conceptual thought which existed in apes even one million years or more after man had branched from the main stem of anthropoid evolution and had acquired lateral characteristics markedly different from those of the apes.

Relevant to the foregoing was the summary of Clark and Piggott (1968) p.22: "Primitive man's cranium was, certainly, as great as ours, and his intellectual capacities innately not inferior, but his social and economic environment imprisoned his capacities in a clamp of iron."

1.1.3.
The concept of artifacts.

Part of the studies of the conceptual processes which might have been used when early-man designed or made an artifact included consideration of the significance of chance. This was dealt with in section 4 of the thesis where the factor of chance was related to the conceptual environment of 'pre-transport' man.

1.1.4.
Anthropological evidence of pre-history handedness.

Sorrell (1968) and Fritsch (1969) referred to research by anthropologists, particularly Mortillet and Sarasin, which had concluded that pre-historic man was, like the apes, ambidexterous. Furthermore, it was possible that there were long periods, (800K-250K), in which left-hand preferring populations were in the majority. The further back in pre-history the greater the indications, according to Sorrell, of left-hand preference. This comment contrasted with that of Annett, Motion (1972) p.355: "... it is extraordinary that no society has been
1.1.5.
Sinistrality to ambidextrality to dextrality.

The evidence for a left-handed society in pre-history had been examined at much length by Sorrell, ibid, and it was possible that some value to the research might have been had from considering his theories that the left-handedness evolved, with time, into ambidextrality and that, in turn, to dextrality. However, for that theory to be acceptable consideration had first to be given to the general evolutionary construct, supra, in which homo-sapiens diverged from the ambidextrous apes and eventually became right-hand and side-preferring. If Sorell's argument were combined with the generally accepted anthropological construct then the result was a chain of: ambidextrality, sinistrality, ambidextrality, dextrality.

The theories that left-hand-preference (LHP) came first, presumably with the man-apes, was supported by those who argued that the present minority LHP population was a vestigial feature of man's past.

Extant cave-drawings were used in the literature which was studied to support the argument that about 100,000 years ago man was still left-hand preferring. Without other evidence that could not be accepted ipso facto. As an example, superstition might have been a dominant influence. Also, in retrospect, there was uncertainty about the relevant behavioural factors, such as hand-eye co-ordination and the conceptual processes, of early man when executing drawings of familiar objects; especially when there was considerable measure of magic in the motivation. It was considered possible that the religious aspects of man's behaviour precluded the use of the preferred-hand and that the left-hand was used to draw with; with the right-side of the body and mind directing the movements of the left-hand. In other words, the left-hand might not
have been the preferred hand for general use. That possibility was supported to some extent by Sorrel's suggestion, in another part of his study, that LHP, per se, was not necessarily a characteristic of all pre-history populations. "His (pre-history man) left-hand, it can be assumed, created the image from a conscious withness which made him (the artist) see his subject with the eyes of a left-handed person".

Overall, modern research indicated a preference of right-hand preferring people to draw the left-profile and left-hand preferring people to draw the right-profile. In section 1.10 further reference was made to artistic motivations.

1.1.6. The conceptual processes and necessity.

Irrespective of the period in pre-history when homo-sapiens emerged, was the fact that the time when man remained a gatherer of food, without the aid of contrived artifacts, was immense. There was, according to Clark and Piggott, an inordinately slow progress with the development of tools; both in their making and in their variety.

About 50K years ago man learnt to control his food supply; thereby steepening the curve of cultural evolution. Oakley, referred to that step forward in culture by comparing tool-making man with those of the preceding period who, despite their artistic skills, were only food-collecting savages.

When describing traditions and inventions of pre-history man, Oakley, ibid, p.78, referred to the fact that the brains of the earliest tool-making homidae (more than one million years back) were probably functionally enough advanced for speech; that is speech using verbalisation and not just grunts and gestures. Although there was no clear evidence
from anthropological and linguistic sources to establish the point in history when speech became general, the rapidity of cultural change in Europe during the Upper Palaeolithic (50K years back) would not have been possible without verbalisation. The ability to conceptualise was demonstrated by the art of the cave-dwellers which reflected primitive man's powers of observation. The ability to observe and record familiar objects was most likely enhanced by the ability to communicate with efficiency. The relevance of that part of the research was its relationship with the studies which had been made by psychologists and linguists of the allocation of the left-cerebral hemisphere to speech functions.

The people of the Upper Palaeolithic not only verbalised but had a varied culture which suggested, according to anthropologists, that there had been time for leisure activities. Evidence of that was obtained from the more orthographic representation of animals and humans of that period.

The step upward in the curve of human evolution, supra, was concerned primarily with the cultivation of food and the domestication of animals so that there was a discernable collection of skills which could be classified as farming. According to Clark and Piggot ibid, that revolution took place in the short span of only 1000 years. It was a cultural change which diversified human life and thought and one which provided stimulation of the development of man's intellectual capacities.

1.1.7.
Religious factors.

The foregoing also gave a step towards considering the evolution of artifacts in greater detail and a step towards the examination of the possible influence on human behaviour of the observation by early man of the passage of the sun and the moon; in the Northern hemisphere, from
East to West 'clockwise'. Some researches, including Sorrell, ibid, postulated that in the middle of the Stone Age (10K to 8K BC) agricultural man lived in matriarchal societies with woman's leading position associated with the earth and moon so that the left-side was given prominence over the right. In contrast, those societies in which the majority of men engaged in hunting animals to provide food and raw materials there was a patriarchal hierarchy with the right-hand and -side dominant; both as a skill factor and as a symbolic factor. Right-hand and-side dominance could be related to sun and moon worship and it is those societies and their artifacts which were given particular study because of their influence on the development of the right-hand-world.

1.1.8.
The Golden Bough.

The many rituals and customs recorded in Frazer's 'Golden Bough' were examined in the light of their occurrence in pre-history; particularly in relation to food-gathering and the religious differences which had been commented upon by Sorrell, ibid.

This aspect of the study of human laterality in pre-transport times, as an influence on the design of artifacts, introduced the sub-subject of the religious ceremonies which might have appeared for the first time when a priestly class evolved during the Neolithic period (c5000BC).* The change in social life which resulted from a greater abundance of food, as indicated by Oakley, ibid, not only gave time for creative activities, but more time in which to expend energy and thought on formal rituals which invoked the gods to maintain the supply of food. The establishment of prescribed ceremonial might have reinforced human lateral preferences; such as turns and circlings in specified directions and the use of a specific hand for symbolic gestures and signs. These might be the progenitures of modern 'transport' side and hand practices.
1.1.9. Directionality in religious ceremonial and symbology.

The swastika symbolised the four seasons. Turning clockwise, the swastika was life-orientated, fertility-granting, auspicious and lucky 'white' magic. ref: Binder (1972) p.23.

When arranged anti-clockwise, that is anti-sunwise, the swastika was considered by the superstitious to represent death, demonism and 'black' magic; as an example, the Tantric cults of India performed ceremonies based on the evil left-hand swastika. Other examples of the allocation of clockwise movement to 'good' and anti-clockwise to 'evil' were: the sunwise passing of the port decanter; the clockwise gyrations of a belly-dancer's stomach; the clockwise circling of Catalanian dances and the sun ceremonies of the Navajo Indians. Apparently the Maypole dances of England were directionally significant with sun and anti-sun movements to represent 'good' and 'evil'.

The relationship between ceremony and transport customs and practices was tenuous. Nevertheless, the ceremonies with their prescribed circlings provided an important link in the causal chain between early man and 'transport' man.

1.1.10. The emergence of an RHP population in the Bronze age.

Sorell, ibid, concluded that the first signs of an RHP population appeared in the Bronze Age (c3000BC); the period of the evolution of the wheel, the potter's wheel, the lathe and the plough. That suggested that the acquisition of a new set of skills for metal working might have
reinforced RHP. Those societies which retained a Neolithic culture might not have acquired the same degree of dextrality. A measure of comparative dextrality might be available from studies of Australian and African aboriginal cultures. Part of the research considered some of the literature on the cultures of the Australian aboriginals and the Bushmen of the Kalahari. (ref.1.4 et seq)

1.1.11.
The emerging right-hand-world from the Bronze Age onwards.

The sickles of the Bronze Age were right-handed. Evidence for this came from researchers who had found sickle blades which had become highly polished on one side from the action of cutting grass; ref: Lewis (1969) p.50. No evidence was found of a left-hand sickle culture; ref: Sorrell, ibid. Before the advent of the bladed sickle, bone and antler artifacts with inserted flints had been used and these were unhanded.

1.1.12.
A determined starting point in history.

From the foregoing studies of the behaviour of man and his culture, c 5000BC was selected as the starting point for examining the evolution of artifacts which led eventually to transport systems. At the same time evidence of human behavioural factors from the preceding million years of human evolution was studied and any applicable evidence noted.

1.1.13.
Summary of sub-section.

(a) The emergence of religions with priests and ceremonies.
(b) The culture and artifacts of the Neolithic Revolution.
(c) The Bronze Age (c3000BC) and the upturn in the curve of technological growth.

Together these three parts of the milestone of human development around 7000 years back argued the case for selecting that period as the
starting point for detailed research into human behaviour and artifacts which would be relevant to the thesis.
1.2.,
The evolution of tools and weapons.

1.2.1.
Introduction.

Tools and weapons were one of the dominant influences on the evolution of man's behaviour and of his customs. The sword dependent customs, from which some of the existing control practices derived, were associated with man's evolving laterality in pre-history.

Tools and weapons evolved in parallel and, with the exception of spears and arrows, many artifacts had a dual purpose so that they could be used also for scraping, banging or cutting so as to make further artifacts.

Primitive man's use of tools gave him competence as a parasite because it enhanced the ability to control his environment and to extend his control over animals and sources of food. A strong right-arm with suitable tools and weapons was worshipped as a source of strength to a community. The combination of tangible and magical properties of the hunter/warrior's strong right-arm may have been one of the earliest of the factors which reinforced the right-hand-world.

Sorrell, ibid, suggested that the use of weapons developed right-handedness as man became aware that his heart beat to the left of his medial. However, that conjecture might have depended on the extent to which early man was accurately aware of the position of his heart.

1.2.2.
Heart-side/Weapon-side.

The following illustrations depict the relationship between 'heart' side and 'weapon' hand and the relationship between the right-arm and the 'weaker' left-arm of a bowman.
Zeus, Artemis and the Amazons were depicted using a bow right-handed and throwing a javelin with the right-hand but early illustrations of right-hand and arm preference may not be conclusive because of 'artists-licence' i.e. bow anomaly. The evidence that Amazonian warriors cut off their right-breasts to facilitate drawing back the bow string, which might have provided a strong example of laterality, has been disputed; particularly by Melegari (1972).

A study of Samurai weapon handling showed strong right-hand preference.

The use of tools and weapons held or operated by the right-hand provided important steps in the evolution of dexterity. However, it was not possible to give any precise period in history when that tendency started, other than the inferred dawn of technology, c5000BC.

1.2.3.
Interim conclusions for sub-section 1.2.

That by 5000BC right-hand preference for tools and weapons was a significant feature of human behaviour which was steadily reinforced as technology improved until the advent of the wheel and transport, in about 3000BC when the trend accelerated.
1.3.
Technology in the Ancient World.

1.3.1.
Introduction.

From the evidence studied the Neolithic period was a clear mark in history leading to the Bronze Age from which the evolution of artifacts, which led eventually to vehicles, could be traced down to modern times. With 5000 years back as the approximate time it coincided with the starting point used by Hodges (1970) and others when surveying the technologies of the ancient world.

When studying evidence of laterality in the artifacts of the ancient world clues were sought from a wide range of tools, weapons, proto-vehicles and such practices as the direction in which ropes were laid. Quoting Hodges, ibid, p.242: "For a technology to thrive and to develop required the presence of other, often quite unrelated, technologies alongside from which ideas could be lent and borrowed." Included in the ideas lent and borrowed might have been traditional customs involving hand- and side-preferences.

Under the heading 'Sources, Place and Time' Hodges emphasized the gaps which existed in the history of industrial archaeology and the inadvisability of trying to fill any gaps by stretching the available information. That warning was applicable to all evidence of early technologies.

1.3.2.
Artifacts in the Ancient World.

Illustrations of carpenters' tools from Egypt c1500BC provided a possible source of handedness preferences in the ancient world. However, none of the tools appeared to be handed. It was concluded that the majority of artists in the ancient world and for many centuries after,
tended to give only an impression of what they had seen and also would distort an illustration to make it fit a given area. This was commented upon by Hodges, ibid, and others.

Therefore the illustrators of the ancient world could not be relied upon to depict the correct relationship between man and his artifacts, (referred to elsewhere as the 'bow anomaly').

Although much of the evidence from the ancient world was centred about the eastern end of the Mediterranean consideration was given also to the technological history of China. The extensive recording and observation of Needham (1965) formed an important part of the research.

Needham, ibid, made no direct observations concerning the handedness of artifacts in ancient Chinese technology and culture but the extensive illustrations to his survey provided evidence of the way in which the Chinese used tools and operated river craft, built and controlled land transport. Handedness in the form of dextrality was evident from a study of the illustrations. For this thesis an important relationship was that which existed between dextrality and the vertical writing format of the Chinese ideograms. The vertical writing did not appear to have reinforced the conceptual processes to the same extent as had the dextrad writing form in the occident.

The study of the illustrations in the literature researched showed that in the ancient world, c5000 years back, the general pattern of behaviour was the use of the right hand for: bowing drills, graving, spear throwing, flaking, paddling, shaving, sawing and operating twist drills and presses. The evidence studied did not negate the assumption that dextrality was a feature of the ancient world and had completely superseded any sinastrality which might have existed at times in prehistory. However, that assumption had to be qualified by the note that some of the skills depicted were ambidexterous, thereby providing an
indication of the importance of an emerging technology on the laterality characteristics of man. In other words, laterality might not have been pronounced until a skill had to be acquired which required eye-hand coordination combined with relative hand strength.

1.3.3.
Reinforcement of the Right Hand World.

It was considered a possibility that there was correlation between the upsurge in technology which came around the time the wheel was invented (c3000BC) and the number of people in a population acquiring greater skill with the right-hand rather than with the left or equally between left and right. At the same time, the progressively increasing powers of the priestly classes and the imposition of prescribed rituals, might have reinforced the superiority of the right hand. The association of religion, teaching and inventive skills might have been another factor of importance in the reinforcement of the discernable right-hand-world.

Another factor considered was the growth of languages and the dualism of words related to left and right. Language reflected a people's cultural background. In many languages there was a dualism in words for left and right. The right represented permanence, force, power, strength, grace, dexterity, dispatch, godliness, rectitude, truth and sanctity. The left represented: the opposite and the negation of all the attributes of the right. Blau (1926), p.63, referred to: "The distinction between right and left are not confined to single objective orientation but are extensively enmeshed with moral, ethical and religious values".

The establishment of stable languages and the keeping of records occurred around the same period as the formalisation of religious symbology and rituals and the upsurge in technological ability with the invention of
the wheel. In other words, all these factors were separately and in combination reinforcing the growth of a world of technology which might result in a preference for things on the right rather than on the left. However, among all those influences the Olympic left-circling and those religious circlings which were anti-sunwise appeared to give a contrary influence on man and the development of artifacts and behaviour which remained in force until modern times.
1.4.

Heliotropic circling as an origin of laterality.

1.4.1.
Left-hand and right-hand communities.

It was noted that some researchers had referred to sun-worship as a possible origin of human lateral preference. Although the facts appeared to fit the argument a study of religious customs, including the many described in Frazer's 'Golden Bough', did not provide clear evidence of a significant number of ceremonies in which the general direction of turning followed the movement of the sun in the Northern Hemisphere; despite the extent of sun-worship, as described, for example, by Hawkes (1962).

One explanation considered was based on the premise that man's tendency to follow the passage of the sun across the sky was much older than the formalised religions. The innate characteristic of man, particularly 'pre-verbal' man, might have included behaviour analogous to the heliotactic behaviour of some animals.

In section 1.10.2. reference was made to Klee (1961), p.44, in which he referred to "..left-to-right (attraction of heat)... the drive towards heat may predominate". That analysis of tropotactic behaviour suggested possible origins with sun-orientated behaviour.

The significance of Northern sun-worshipping religions to the origins of side and turning preferences of man was related to the start of religions with formal ceremonials and to the advent of the right-hand-preferring (RHP) majority; which may have been about 3000BC.

Considered was the possibility, according to some researchers (e.g. Sorrell, ibid), ref: section 1.1.5. and 1.1.7, that the majority of human beings were left-handed and left-side preferring in the food gathering communities, which preceded the hunting societies. Such
left-preferences were contrary to the sun direction and suggested that man was unaware of the sun's movement. This was a concept which was difficult to accept because the majority of records showed that man in all parts of the world was well aware of the diurnal procession of the life-giving star. (ref. Hawkes, ibid.). In turn, it was difficult to conceive any primitive religion which did not take some account of the movement of the sun.

1.4.2.
Southern Hemisphere.

Consideration was given to the 'reversed' path of the sun across the skies of the Southern Hemisphere in relation to the extant Neolithic culture of the aboriginal Australians. See fig. 1.4.2.

The insecurity of the aboriginal Australians' way of life caused them to devote much of their time and energy to ritual activities. If, as postulated by Clark and Piggott, ibid, they represented the behaviour of stone-age man and as ritual played an important part in daily life, then that ritual was studied in association with their artifacts in order to check for any behaviour related to sun-circling movements.
1.4.3. Australian aboriginal and Bushman culture.

No evidence of extreme sinistrality was found from studying records of aboriginal ceremony and artifacts. In general, they were either ambidexterous or dextral, (Gould 1969).

No evidence was found of a tendency for the left-turn and the left-hand, to predominate in Aboriginal societies. This was examined in the light of the evidence which showed that when man, the hunter and food-gatherer, emerged as a species and extended his territory from the Northern hemisphere, Southern Australia was one of the last areas to be explored. This suggested that rituals, such as sun-worship, established after the Middle Pleistocene period, could have been carried across to the Australian continent. Perhaps, of greater significance was the great disparity in size between populations of the Northern as opposed to the Southern hemisphere. That argued that even if significant ritualistic handedness factors were found in Southern rituals they could not, because of their isolation - both geographically and evolutionary, be of consequence when trying to determine the origins of handedness in artifacts.

This particular study of the possible influence of 'sun' religions on human behaviour suggested that, in Australia in particular and possibly elsewhere in general, the inherited traditions from right-hand preferring Pithecanthropus dominated. Therefore, as suggested supra, innate and learnt hand preference factors dominated the religious influences. However, the influence of sun worship ceremonial could not be completely dismissed as, either as a coincidence or as reinforcement of a human characteristic, it fitted into patterns of evolutionary behaviour in which man interfaced with his artifacts.
Another extant stone age society was that of the Bushmen of the Kalahari. A study of Bushman artifacts and ceremonies was another possible area of research which was considered (van der Post 1961).

1.4.4. Olympic circling.

In contrast to the sun-circling customs, the Olympic athletic events of ancient Greece were run anti-sunwise and since that time the custom for the majority of track events was to circle to the left. The 'Olympic' direction around a track was adopted for other types of competitive events and in recent times for motor-racing circuits. Even the Indianapolis motor racing circuit in North America was run anti-clockwise in a population which had no particular incentive to copy European tradition. It was inferred that the Indianapolis track circling direction was based on the international left circling of circuses which in turn derived from the Olympics.

The Indianapolis race-track was chosen as an example because of the background in which many traditions acquired from the Old World had been abandoned or reversed.

World-wide, circuses, many horse-racing tracks, early aviation meetings as well as skating rinks subscribed to the anti-clockwise circling as the accepted direction. A cursory study of movements in dancing provided no significant evidence of pronounced directionality.

The research considered the possible reasons for the preferred left-circling of the Greek athletes.

Without the impediment of clothing there appeared to be no artificial constraints on the direction of circling. The only evidence on the subject was that of illustrations.
One conjecture considered was that anthropometric bilateral asymmetry, with the right leg stronger than the left in the majority of athletes, favoured circling to the left. However, this has been disputed because the differences in reach and strength of the left and right legs are very small and not likely to dispose a person to prefer one direction of turning to the other.

A behavioural factor which might have been of greater significance in influencing the direction of running in the Greek stadia derived from social custom and the symbolic differences which existed between the left and right sides of the human body.

If it were acceptable conjecture that the principal spectators, the officials and noblemen, watched the athletic events from the outside of the track then polite custom might have dictated that competitors should pass the reviewing podium on their right-hand with the result that they had to circle anti-clockwise.*

A similar anti-clockwise circling practice was seen with present-day military ceremony; such as the Trooping the Colour march past when the troops pass in front of the Sovereign from her left-front to right-front and with the senior formations on the right of the parade. However, the anti-clockwise direction was not invariable because topographical situations sometimes dictated clockwise circling.

* The Panathenaic Amphora, showing men racing, indicates anti-sun circling.
1.5.
Handedness of artifacts.

1.5.1.
Ploughs.

A specific area of research into the evolution of artifacts related to agricultural ploughs.

Ploughs had been in use in many parts of the world from as far back at least as 3000 BC.

The majority of single ploughs researched were shaped so that the share cut and the mould-board threw the soil to the right of the line of advance. That fact was examined to see if it was an example of the influence of dextrality on the design of agricultural implements. For the purpose of this study a plough was classified as a vehicle.

The evidence studied was that of models and exhibits in museums, the Science Museum, London, in particular, and illustrations in the relevant literature. The models studied represented agricultural practice from the following parts of the world:

- United Kingdom
- Russia
- Germany
- Italy
- Bulgaria and Asia Minor
- Africa and South Africa
- Siberia
- Siam
- Spain
- North America

The list did not include South America and India.

Although no evidence was available from the models and the literature to indicate that there had been a significant number of sinistral ploughs, nevertheless the reversible-throw ploughs used for contour ploughing had to be included to set against the generalisation of the dextral ploughs. It was noted that modern gang-ploughs were available for both left and right throw.
Consideration was given to the hypothesis that the dextrad plough was derived from early artifacts used to groove the soil before planting seeds. It was considered that a right-hand preferring population of cultivators would have used a furrow making tool in such a manner that the action and the angle of the tool relative to the line of advance had provided a model for the first plough maker; as illustrated in fig. 1.5.1.

Tests with a piece of wood held as in fig. 1.5.1 showed that the soil was thrown equally to each side and that the distribution of the soil did not vary with the handedness of the operator. Therefore, the foregoing was not considered of significance as evidence for the evolution of the handed plough. Illustrations of primitive ploughing, using human or animal power, showed that the share was nothing more than a grooving device made from a branch fixed in a near vertical position on a frame. This primitive plough had an unhanded soil throwing action.

Hodges (ibid) p.76 "The earliest form of plough that we know amounts to little more than a forked stick, the two tines of the fork serving as handles and the junction as a share....produced a rather narrow furrow in the soil."

The illustrations of primitive ploughs which were studied did not indicate any significant handedness factors. Although the primitive plough did not provide evidence of primitive man's laterality it was nevertheless a useful subject for further research if it were accepted
that the plough could be classified as a proto-vehicle.

Between 2000 and 1500BC, in Mesopotamia, the plough was given a sole which improved its action. Again there is no evidence of handedness. This did not appear until the mould-board was devised to throw the soil to one side, so that the argument that primitive grooving tools, used in a right-hand preference posture, were the progenitors of a handed plough was negated. It was noted that the breast plough was unhanded in design and action.

Celtic tribes, invading Britain about 500BC, introduced the heavy ox-plough equipped with a mould-board for turning the furrow. To which side did it turn the furrow? The answer was not definitive and therefore it could not be concluded that it was to the right. Seebohm (1952) p.284, referred to contour ploughing, c 100BC, using a mould-board plough which always turned the furrow downhill. That envisaged a variable-hand mould-board so that there was no question of human hand-preference influencing the design of the artifact.

It was noted that the pre-Roman plough of the Celts did not always have a mould-board and therefore the furrow was not turned and the ground had to be ploughed a second time at right angles to the first rows or furrows.

Historians of the plough showed that there were numerous types and variations of plough. Therefore it was concluded that there were also many variations in detail design which may have included both 'right' and 'left' handed ploughs.

1.5.2.
Agricultural machinery.

A survey was made of agricultural machines hauled by animals in order to determine any significant side and hand preferences. Many of the horse-drawn machines studied had an operator's position to one side of the medial:
the reaper, sheaf-binder and similar machines. The majority were 'right-handed' in their action; that is the operator and the draught animal were to the left of the medial. Primary references were: Seebohm (1952) and Fussell (1965).

The 'blade' type implements which operated as cutting devices were often 'right-handed'. This was inferred as an example of a manual device influencing a mechanical system. In this case the scythe, which was arranged for use as a right-side sweeping cut, made anti-clockwise. In general, agricultural machinery and vehicles exhibited a degree of ambivalence of design, which with the exception of the above did not usually perpetuate the right-handedness of manual implements. Furthermore, agricultural machines did not travel on the highway for great distances, nor in the company of other machines, so that customs and rules did not follow from which there might have evolved significant hand- and side-preferences.

1.5.3.
Clock face.

One of the first instruments to be designed and built in sufficient numbers to qualify as a stereotype was the clock. The directionality of the numerals and the rotation of the hands followed the order of a sundial markings and the movement of the sun-shadow.

In those parts of the thesis in which the dextrad writing form was used as a basis for tracing the influence of the right-hand-world on man's nature and nurture, the clock was included as a contributing artifact to the left-right directionality and the origin of the clock-wise for increasing value stereotype. The clock face and hands became the prototype for the dial type instruments which eventually became a characteristic feature of man/machine interfaces and, with few exceptions,
dial instruments were arranged whenever possible to conform to the clockwise for increasing value stereotype so that the influence on human directionality was dextrally reinforcing. It was noted that in geometry angular values increased anticlockwise.

1.5.4. The Sword.

The sword which evolved as a personal weapon and as an extra corporeal limb, was the basic close-combat weapon. It was also of a size which enabled it to be carried either in the hand or in a 'non-aggressive' position in a sling or scabbard at the warrior's side. The wearing of a sword by horse riders is the start of a clear and, as proposed, a very important evolutionary chain which led from pre-history to space flight; even though the sword was now carried only for ceremonial occasions.

The combination of sword and scabbard (S/S) provided a key point in the study of the influence of human laterality on the design and use of artifacts. It dictated the side on which a horse could be mounted and, as discussed in section 3.2, may have been an origin of the 'keep-left' rule-of-the-road.

The sword and other hand weapons in conjunction with a shield provided an example of the 'skewed' ergosphere which might have influenced the design and operation of vehicles.
1.6. **Summary of historical evidence of Handedness.**

The notes gathered contained many references to handedness in pre-history and in the period around 3,000 BC; the dawn of technology. The arguments put forward that, at different periods, during the evolution of modern man, the preferred hand of the majority has sometimes been the left and sometimes the right, were not considered to be of direct significance to the subject of this thesis. The reason for the foregoing conclusion: by the time of the emergence of stereotyped artifacts and proto-vehicles and craft there was a majority right-hand-preferring population. Therefore the thesis was based on the evidence of an RHP population's artifacts as related to the following:

(a) The northern populations inherited religious and traditional ceremonies derived possibly from sun-worshipping religions which were the origins of 'good' and 'superior' turns to the right and sunwise (clockwise) circling; as opposed to turns towards the non-preferred hand. Therefore, the statements by Sorrell concerning sinistrality were largely discounted. Not because they might have been wrong but because the period to which they referred was outside the history of 'technological' man.

(b) The anti-sun circling Olympics remained an influence on all types of track events to the present day and also influenced automobile and aviation racing and conduct.

(c) The sword and the clock were two particular artifacts which were used as key factors of influence which started causal chains whose effects were still apparent in modern man/machine interfaces.

(d) A key assumption made at the end of section 1.5 was that right-hand and side-preferring man constructed and operated vehicles and that any
evidence, in pre-vehicle populations, of a 'left-hand' population could be set aside as isolated branches from the main stem of evolution. There was no evidence of left-hand and left-side preferring societies contributing significantly to the influence of hand- and side-preference on vehicle controls and conduct.

The evidence for the foregoing was the extant 'right-hand' world in which the number of 'right-hand' artifacts exceeded significantly the number of left-hand' artifacts; there were also a significant number of 'ambidexterous' artifacts whose design has not required any consideration of the handedness of the user.
1.7.

Modern Research into Laterality

1.7.1.a.

Introduction.

This was an area of research which provided a large number of references to studies of human laterality, handedness and side preferences but only a few references to the study of those factors in specific man/machine interfaces. The sparsity of specific evidence led to the inference that the subject of laterality in man/machine interfaces was not generally considered to be of importance; as noted in the Introduction to this thesis.

1.7.1.b.

Introduction to studies of human laterality and operating environments.

The molar of the present day handedness as an environment was clearly discernable as the right-hand-world. It was not considered necessary to provide specific evidence of this. Traditions, customs, habits, social behaviour, preferences, artifacts and vehicles and the way in which vehicles were controlled all testified to the extent of the right-hand-world and to the fact that whenever man had been faced with a simple choice between left and right, the right and the dextrad arrangements tended to dominate those of the left.

In general the contrived environment reflected the right-hand preference of man.

In the natural environment nature had selected a more symmetrical approach. Asymmetrical forms usually occurred only when the ecology was not symmetrically presented to the living forms. As an example, plants sought the direction of the sun. In some instances man had behavioural patterns which were sun-orientated, in others he was influenced by the molar environment and its dominating features and patterning.
Fritsch (1968) discussed the ambivalence of nature and commented, p.8, "...that Nature, though she may perhaps distinguish between right and left, shows no actual preference for either of them....".

Gardner (1967) pp.61-62, said "Helices abound in the plant world, not only in stalks, stems and tendrils but also in the structure of myrids of seeds.... as well as in the helical arrangement of leaves around a stalk.... the majority of twining plants.... coil in right-hand helices, but there are thousands that coil the opposite way."

The importance of asymmetry in the environment was emphasized by the study made of conflict and arousal by Berlyne (1966) in which he observed the comparatively greater arousal effect of asymmetrical patterns when compared with symmetrical patterns. This indicated that asymmetry of patterning and spatial order in man/machine interfaces might dominate other lateral factors. In section 1.10 under the heading 'directionality' the thesis considers some of the psychological aspects of human behaviour in the interface.

1.7.2. Definitions of laterality.

Definitions of laterality and in particular dextrality were considered as essential basic references.

In order to balance the evidence, a definition of sinistrality was included as follows: Sir Cyril Burt's definition of left-handedness, as quoted by Barsley (1966), "A consistent tendency (whether congenital, or induced post-natally by accident or by some other change in the hand or its neuro-muscular apparatus) to undertake new dexterities with the left-hand rather than the right". Barsley, ibid, p.201, pointed out that Burt's laterality observations indicated that the detection of left-handedness did not depend only on the spontaneous reactions of a child when asked to perform a certain task, or when left to perform it alone. It was not enough to ask which limb was uppermost, as in folding the arms, crossing the legs or clasping the hands. The important question which
had to be asked concerned which of the hands executed the more
delicate task of directing the artifact.

The foregoing observations were considered when studying both
delicate and active control tasks as well as the less delicate and
occasional tasks involved in the control of different types of vehicles.
The joystick type of control lever was a particular example studied
because of its wide application to vehicles and to man/machine arti-
faces classified by this thesis as quasi-vehicular.

Another important type of interface studied, because of the hand-
edness factors involved - particularly the distribution of manual
dexterity, was the keyboard. It was noted that keyboard interfaces
were one type in which the operator was sometimes required to make
two responses to a display/control scenario at the same time. Dimond
(1970) found that the responses of the hand appearing second in the
sequence might be considerably delayed.

1.7.3.
Lateral asymmetry.

The definition right-hand-world (RHW) was used throughout the
research as a generalised description which could be related to the
records and practices researched from the available literature.
However, in some respects, RHW was a crude definition which although
it matched the choice factor between left and right when designing
a control interface, nevertheless it could not be applied directly to
the human component. This was emphasized when relating the observations
of Clark (1957), on the distribution of laterality, to the study of
specific man/machine interfaces. Clark emphasized that there was no
dichotomous distribution between right-hand preference (RHP) and
left-hand preference (LHP). That aspect was taken further by Annett
(1972) under the title 'The distribution of manual asymmetry' and by

Annett, ibid, classified handedness into: (a) the differences between the hands in skill; (b) hand preferences for common unimanual tasks; (c) the distribution of types of preference in the population and (d) the distribution of preference in families. Of those classes all but the last were used as basic references when studying specific control situations.

In section 1.1.8. et seq, in which the results of studying handedness and the evolution of artifacts in history are recorded, reference was made to the social or cultural influences on the evolution of stereotypes. Relevant to those factors were Annett's, ibid, observations on the origins of handedness: "Genetic, accidental and cultural factors all have a role in the development of handedness and the basic characteristics of human laterality is that of a normal distribution of differences between the sides arising, probably from accidental influences in early development. The chance combination of factors which incline one side to be more efficient than the other, both sides having an equal chance of being favoured, is sufficient to account for the basic distribution of lateral differences in the human".

Part of the research involved a study of animal navigation and particularly of that part of animal behaviour which was dominated by the sun-seeking senses.

If heliotropic animal navigation systems were uncompensated by an internal 'clock' and homeostasis it was inferred that movement would be roughly in a circle to the right in the Northern Hemisphere and to the left in the other hemisphere.
Arising from the foregoing was consideration of any evidence which suggested that man had hereditary behavioural characteristics which came from simpler forms of life; characteristics which manifested as a predilection for turning or circling in a preferred direction.

The available evidence of human behaviour was not sufficient or substantive enough to support the theory that a preference for turning to the right or circling to the right could be traced to innate characteristics. Traditions and customs provided many examples of preferred directionality, sometimes to the left sometimes to the right, as described in section 1.4 et seq, but no general pattern of behaviour could be established which was innate.

Loveless (1962) referred to the tendency in a display/control relationship of "turn clockwise for anything" and Holding (1957) pp.93-97 "the clockwise tendency was less marked in those with left-hand preference."

1.7.4.
The origins of bilateral asymmetry in man.

From the origins of bilateral asymmetry researched and the tendency to make preferred turns and control movements, the only origin which was acceptable as a basic factor in the thesis was culture and the related social environments. At the same time the possible relationship between handedness and bilateral cerebral functions was not neglected because the emergence of speech, supra 1.3. et seq, provided a milestone in the evolution of man which could be related to the emergence of contrived or conceptualised artifacts.

1.7.5.
Side dominance in children.

Records of the behavioural patterns of infants, as described by Gessell (1966) and Giesecke (1936), showed a variation in the lateral
activity of the hands, legs, trunk and head. The degree of fluctuation between one side and the other varied from one infant to another and was most pronounced from 7 and 10 months. Most significantly the degree of fluctuation was inversely proportional to the strength of side-dominance. It was suggested by Giesecke that hand-preference made its appearance during the second half-year of life and was most apparent after two years. Studies in distance reaching showed a preference for using the right hand along with the ability to reach faster and straighter with that hand compared with the left hand.

According to Gessell, ibid, investigators had found that there was an increase in hand skill/strength compared with that of the left by right-hand preferring pre-school children. It was assumed for this research that Gessell was pointing to the influence of handwriting when he referred to the pre-school groups of subjects because in the same study he emphasized that ambilaterals tended to be retarded in early language development and that that condition lasted until such time as there was a strong unilateral dominance acquired from learning a specific skill. That observation was applicable directly to the studies which were made for this thesis of the influence of the dextrad writing form on the conception of control equipment arrangements in control interfaces.

The dextrad conceptual and skill factors were alluded to by Gessell when he observed that tests of pre-school children (viz 4 to 5 years old) indicated a preference for drawing vertical lines downwards and horizontal lines from left-to-right. The last point was related to the concept of the influence of the dextrad writing form and to the arrangement of control units in a serial order.

The pilot studies of the arrangement of the controls of a crane described in section 4, were prompted in part by studying the work of
Gessell and others working in the field of child development.

The right-hand-world was referred to by Annett, ibid, when commenting on the conformity with the dextral majority as a social pressure. The dextral majority was a factor which inclined the distribution of lateral differences towards the greater skill on the right. Furthermore, the factor of conformity probably had a genetic foundation.

It was noted that Jersild (1969) listed the origins of handedness as:

(a) inherited
(b) physical differences between the sides of the body
(c) chance
(d) the right-hand-world

Jersild summarized his findings by stating that it seemed likely that hand-preference was the outcome of a combination of genetic factors and a child's early training.

Fritsch (1968), p.121 et seq, provided one summary of the origins of human laterality. He referred to three possible basic origins: heredity, environment and pre-natal conditions. He proposed that in former times the environmentalists had carried the most weight because the concepts of heredity had not been fully developed. In modern times, according to Fritsch, the contrast between heredity and environment as theories had become less defined.

1.7.6.
Cerebral dominance.

A study was made of literature on cerebral dominance and the speech centres. It was noted that the majority of human beings were probably influenced towards the right-hand by the development of speech function in the left-hemisphere of the brain. However, although the research into speech-centre influences on human behaviour were extensive, they were, in
Annett's, ibid, summary of her study of the distribution of manual asymmetry concluded that human handedness depended on two factors. One factor was accidental and congenital but non-genetic and the other was possibly genetic but modified by cultural influences. The right-hand-world, in the context of this thesis, arose directly from the second of the two factors because culture was a primary reinforcing process in the generalised behaviour of a population.

Millar, ibid, concluded from studies made of the lateral specialisation of the human brain, which replicated in part Levy's (1969) experiment, that real differences in ability between right-hand and mixed-hand subjects existed and that they reflected, probably, underlying differences in the asymmetrical organisation of the brain's functions. In that context Annett (1970) p.556, concluded that: "As to the nature of lateral asymmetry, it appears that hand preference is closely linked with asymmetries of manual skill. The latter are normally distributed, stable during growth and slightly greater in females than males. That combination of findings suggested that lateral preferences arose primarily from asymmetry of the neuro-muscular coordination which has an enduring role in manual control."

A significant comment by Millar, ibid, was that pure left-handers would be expected to show a similar pattern of abilities to right-handers. However, as pure left-handers made up only 4% of a population it was not practicable to test that argument.

1.7.7.
Frequency of sinistrality.

Annett (1970) considered the advantages of dextrality which might have contributed to the selection of factors for right-handedness at the expense of those for the left. There was no evidence, according to Annett,
that the frequency of sinistrality had decreased in historical times. (Brain 1961 and Dennis 1958). Stability might be due to the fact that preference was irrelevant to survival or might be due to selective advantages in those with tendencies for left-preference. No examples of vehicular man/machine interfaces were found in which the configuration of the controls or of the operating environment favoured a sinistral operator; even after learning and adaptability. Only in the non-vehicular interfaces was there an example - the QWERTY keyboard of the typewriter and other alphanumeric interfaces. However, Annett's, ibid, comment on the relationship of sinistrality to the evolution of man and artifacts was considered with respect to the modern tendency for man/machine interfaces to become symmetrical instead of handed. (see also section 4).

The conclusion that there had been no decrease in the frequency of sinistrality in historical times was related to the possible degree of influence of the RHW on innate and maturing handedness character-istics. It was considered possible that as the RHW was only a small span in time within the total history of man and artifacts then it was too soon for any tendency to emerge. It was possible that after another 10,000 years of man/machine interfaces, particularly interfaces which were either ambidexterous or dextrad, the frequency of sinistrality might reduce.

1.7,8.
Male and female operators.

During the research only a secondary study was made of the differences in performance between male and female operators in a control interface and of the differences between male and female handedness factors and distribution; as referred to by Annett (1970).

One conclusion examined was by Culver et al (1970) on evoked cortical potentials and hand- and eye-dominance because of the possible
implications to societies in which females increasingly undertook machine control tasks. Culver et al examined the amplitude and symmetry of right-and-left occipital-lobe evoked potentials to right and left visual-field stimulation as a function of hand- and eye-dominance in females. For all subjects, the right-lobe amplitudes were greater than those of the left-lobe during stimulation by the left-visual field but not by the right-visual field. Left-eyed subjects had significantly greater evoked potentials than right-eyed subjects. The authors compared their study with others and concluded that there was a sex difference in the relationship of handedness to right-lobe/left-lobe symmetry.

(Gibbs (1965) referred to results of skill testing in which the difference between the scores of female and male subjects gave a \(p < 0.01\).)

Pilot studies are described in section 4 which involve both male and female subjects in a simulated control situation and the foregoing factors therefore, will have to be included in any full scale results analysis.
1.8.

Handedness characteristics and interface factors.

1.8.1.

Introduction.

Preferred and non-preferred hand controls.

The literature studied showed that data on preferred directions of movement for controls was, in general, derived from research with right-hand preferring subjects. However, Chapanis and Gropper (1967) studied some common control/display (CD) movement stereotypes for 32 RH and 32 LH subjects. Operators were required to make settings with both their right and left hands on horizontal and vertical dials. The relationships between the movements of a knob and the movement of the pointer on a dial were varied systematically. It was found that there were significant differences in the time taken to make settings and in the number of errors in the initial direction of turn and that they were a function of the handedness of the subjects and the hand used.

Loveless (1962) and Clark (1957) had considered the effect of the hand employed to make responses in display-control (DC) situations in the light of possible differences in operator performance between the preferred and the non-preferred hand and between overtly right- and overtly left-handed subjects.

It was noted that the effect of bilateral body symmetry might result in symmetrical rather than corresponding movements of the non-preferred hand following directional training for the preferred hand. Supination of the preferred hand was matched by supination of the non-preferred hand and, because supination was generally an easier wrist movement, it was likely that this was a significant factor in behavioural characteristics of a subject conceptualising or arranging a man/machine interface.

Examples existed of man/machine interfaces in which the orientation of the controls and their directions of motion required simultaneous hand
movements by the operator in which one hand supinated and the other
pronated; a combination which for some complex DC relationships involved
the acquisition of a special skill.

1.8.2.
The origins of direction of motion stereotypes.

Loveless, ibid, commented on the preferred direction of hand
motion in control situations as the possible origin of direction of motion
stereotypes. Furthermore, when dealing with the influence of handedness
Loveless referred to stereotypes which might have derived largely from
experience of natural phenomena or cultural conventions. That comment
appeared to support the general argument that human lateral preference
characteristics contributed to the bilateral asymmetry of many vehicle
control interfaces.

Loveless referred to display/control relationships as 'direct' if
a given control movement produced a pointer movement in the same direction
and 'reversed' if the opposite sense resulted. Direct DC relationships
were clearly related to eye/hand coordinations which had been practised
from birth. However, some DC stereotypes did not appear naturally and
might reflect conventions prevalent in the culture to which the operator
belonged. It was suggested by Loveless that such stereotypes might be
referred to as 'expected', 'preferred' or 'dominant'.

Among the control positions examined during the research there were
examples of both 'direct' and 'indirect'. Those arrangements which were
classified as incompatible were those in which the operator had to use the
non-preferred or both hands or was required to perform control selections
and operations at great speed. However, experience of incompatible DC
relationships was sometimes difficult to obtain from the literature or
from practical tests because, as pointed out by Loveless, ibid, once an
operator had settled into a continuous DC task the effects of an incompatible
arrangement were overcome.
influence of learning and the adaptability of the human operator which, in general, tended to mask any evidence of the influence of human laterality.

1.8.3.
Hand-preferences and DC stereotypes.

Another source of references to the study of DC stereotypes was Murrell (1965).

In many of the man/machine interfaces studied during the research for this thesis there were strong DC relationships or stereotypes. These were considered in the light of Murrell's observations; particularly pp.229-239, where he considered the relationships between display and control. It was noted that the DC relationship would be the same whichever hand were used because the relationship involved the physical movement of two parts. Furthermore, the expected DC relationships would be unaffected by hand-preference. For example, in a follow-the-pointer task no significant difference was noted in the laboratory tests between LH and RH subjects or when the non-preferred hand of an LHP or RHP was used.*

Murrell provided another reference to the influence of the right-hand-world when he referred to tests which showed that LHPs were better able to use their non-preferred hands than were RHPs because the circumstances of the right-hand-world had forced them to adapt.

1.8.4.
The reversal of DC stereotypes.

In sections 3.1 and 3.5 the reversal of DC stereotypes was considered in relation to specific ship and aircraft control equipment. This was done as one way of determining the strength of assumed causal chains of control evolution.

*Annett (1970) & Loveless (1962) referred to: sinistrals exercising a manual skill in a DC relationship equivalent to a dextral if the controls were matched to an operator's hand preference; controls which were significantly handed could not be used to the same degree of skill by an operator having the opposite hand preference.
1.8.5.
Preferred and non-preferred hand performances.

The literature which was studied indicated that differences in performance between the preferred (PH) and the non-preferred hand (NHP) varied considerably from one task to another. The cause was sometimes asymmetry of anatomical features, sometimes the result of differential training; ref Provins 1956.*

When control tasks required the use of the NHP or coordinated and simultaneous use of both hands, then the effects of incompatible DC relationships were more prominent.

Loveless, ibid, provided a key reference on the relationship between handedness and DC stereotypes: "On the present evidence, therefore, it would seem that as long as well-marked stereotypes are used, there is little risk in assigning controls to the left hand; though in view of the known effects of stress, it might be wise to assign critical controls to the RH wherever possible."

Relevant to the foregoing observation was Annett (1970), pp.545-558, "A linear relationship between degrees of preference and degrees of manual skill was demonstrated".

This was illustrated by the following diagram based on that in Annett's paper (fig.2):

![Diagram showing the relationship between hand preference and performance between preferred and non-preferred hands.](Based on Fig.2 of Annett(1970))

*Training for skilled tasks such as typewriting (Provins & Glencross 1968) can equalise the performance of the two sides but it is possible that the non-preferred hand takes longer to reach a standard comparable with that of the preferred*.
1.9. Early man/machine interfaces, handedness and dextrad forms.

1.9.1. Handedness factors in early man/machine interfaces.

The examples listed in the previous section included animals as a form of vehicle within the definition used for this thesis. The horse and rider combination provided an important starting point in the evolution of vehicle control systems and practices. The instrumental part of the man/machine interface in the early systems was made up from the sensory inputs to the operator. The handedness factors were related to the primary control inputs such as reins, sticks and paddles or poles. These control actions are examined and commented upon in sections 3 and 4 under specific vehicle types.

The significance of handedness as the cause of errors in early control interfaces may have been small because there was no analogous instrumental interface, as with many later types of vehicle, so that the operator's reaction to events was directly through the sensory inputs.

The importance of research into early man/machine interfaces was that of emphasizing the pronounced changes which came about when vehicles were equipped with controls and instruments which, for cost and mechanical reasons, had to be placed to one side of the medial and related to the handedness of the right-hand-preferring (RHP) population with little attention given to the smaller LHP population.

1.9.2. The influence of dextrad writing forms.

By the time man/machine interfaces, both vehicular and non-vehicular, were a common feature of the more progressive cultures the dextrad writing form was also a feature of many populations.* The possible relationship of non-dextrad forms was not neglected and attention was paid to the

* The Greek Baustrophedon, left-right, right-left, writing form was replaced by the dextrad form about 500 BC; ref: Neal (1963) p.40
technology and culture of China to see if there were any control preference features which related to the vertical order of Chinese ideograms. (ref: Needham 1965).

In those populations with a dextrad writing form this research concluded that not only did this act as one of the reinforcing factors to the right-hand-world but was a fundamental part of the study of human behaviour when conceptualising a control interface. The extent of this influence was not clearly defined by the literature examined and therefore this was made the basis of pilot studies described in section 4.

Reference was made at the beginning of this section to Clark (1957) and the observation that there was not a dichotamous classification of right and left handedness. In that connection Clark also observed that the preponderance of LHPs was greatest in those activities not connected with school writing. In other words some proportion of those classified to the left of the normal distribution of manual asymmetry, as described by Annett (1972), used their right hand for writing. This suggested that many of those operators who might have been classified as LH dominant might approach a man/machine control interface with the dextrad writing form as a primary influence. (ref: Pilot experiments, Section 4 App.A)

Kimura and Vanderwolf (1970) referred to the importance of writing in the study of hand-preference and skill. They concluded that hand-preference referred to the consistent preference for one hand when performing a number of commonly executed learned acts; the most important being handwriting. At the same time little was known about either the nature of the motor skills involved or about the nature of the motor-dominance which was described as hand-preference. In an initial attempt to find out how the two hands of a subject compared, Kimura et al studied the individual finger movements because that was a demanding type of motor
task and also because other researchers had assumed a relationship between hand-preference and the ability to make fine movements.

When relating the foregoing specific study to the thesis the reference to hand-preference for fine movements was important because most control interfaces could be classified either as those which required coarse hand movements or those which required fine movements; although some interfaces involved both types of movement for different operating circumstances.

Reference was made supra to the dextrad handwriting and printing as one of the reinforcing factors to the right-hand-world. When reaching that conclusion cognisance was given to its relationship with the sword/scabbard factor referred to in section 1.5.4.

The sword/scabbard factor, as an origin for practices which may have influenced side preferences in transport, was assumed to have been established well before man evolved vehicles, control positions and practices. Eventually this factor came to exist side by side with the dextrad writing form and it is not always possible to see which of these two factors, themselves interdependent, had exerted the greater influence.

In addition there was the influence of the generally accepted left-to-right serial order of ascending numbers, the serial order of the alphabet and the directionality of the clock which acted as reinforcements to the right-hand-world.

1.9.3. Interim conclusions.

The most probable order of influences on the design of vehicle controls and side preferences in transport was:

First, the right-hand-world of artifacts as a molar environment; second, the influence of the dextrad form for handwriting, the alphabet, numerals and other printed characters but its degree of influence modified
in the light of studies made into human behaviour in the visual environment; third, the sword/scabbard factor as described in sections 1.5.4. and 1.9.2.
Directionality

Other physiological and psychological factors of the man/machine interface are considered in 1.12. This specific sub-section was intended to provide an introduction by concentrating on the visual directionality aspects.

1.10.1 Dextrad perceptual factors.

Consideration was given to that part of human experience which related to the perception of natural and artificial environments; particularly of contrived patterns. The last were represented under the general heading of art.

An important part of the analysis, using perceptual factors, of any asymmetrical pattern was the subjective impression of directionality; primarily left-to-right and right-to-left, from one vertical boundary to the other. The dextrad writing process was assumed to impose a behavioural pattern on the observer such that, in the absence of dominating, directional-patterning, a picture, for example, was scanned from left to right. The influence of the dextrad writing process was noted in Arnheim (1969) pp.22 et seq where the visual perceptual factors of visual balance, as described by Wölfflin (1941), were considered. The basis of Arnheim's dissertation was that pictures changed appearance and lost their meaning when viewed as mirror images. That effect was attributed to the influence on the perceptual behaviour of an observer of the dextrad writing form. That influence was applicable also to the subjective effect of the diagonal of the design which usually ran from bottom-left to top-right in a picture. Arnheim cited examples of paintings which, when inverted or reversed laterally, exhibited significant effects of unbalance. Gaffron (1950) was referred to by Arnheim in the
the observer experiences a picture as if he were facing his left side. He (the observer) is subjectively identified with the left and whatever appears in that part of the picture assumes greatest importance. Gaffron's conclusion was related by Arnheim to the observation by Dean (1946) about the stage areas of the theatre in which as the curtain rises the audience can be seen to look to its left first. The left-side (to the audience) of the stage was considered the stronger. In a group of two or three actors, the one to the left-side of the stage dominated the scene.

The foregoing observations correlated with the evidence of interpersonal behavioural factors related to social precedence and the direction in which the Olympic athletes passed the spectators and judges. (This aspect of directionality was reviewed in Section 1.2.)

1.10.2. Directionality in Art and in Perceptual Processes.

Klee (1961) p.7, illustrated the protogenesis of form by drawing linear forms from left to right, even though the objective of the illustration would have been just as well met had the directionality been the other way. On page 9, ibid; the illustration of 'Chaos; Disorder, Cosmos and Order' was dextrad in form; again, it could have been drawn the other way. On page 16, ibid, 'Good and Evil', the directionality was dextrad for the principal movement.

There were other examples of the dextrad form used by Klee, ibid, when illustrating his concept of "the point that sets itself in motion".

Relative to the study of directionality, as a dominant factor during the performance of perceptual skills, was Klee's, ibid, question on spatial determination of a point on a bounded plane: "What enters and where does it enter?" (ref. p.39). In Section 4 of the thesis, pilot studies were described which were covertly related to Klee's question. The studies
concerned spatial determination when conceptualising the relative positions of controls.

When describing his synthesis of 'objective body' and 'subjective space' Klee, ibid, p.44, referred to: "In left-to-right (attraction of heat), the direction is free and the drive towards heat may predominate", Klee was emphasising the accent on the direction of left-to-right and postulated that left was cold and right was warm. (ref: Fig 1.12.3) Fritsch (1968), p.85, gave a less enthusiastic view of directionality in art when he examined Wölflinn's, supra, observations because he considered them to be not necessarily precise. However, Fritsch did admit: "... in figure painting we tend to look for the centre of gravity, if not in the middle then towards the top right hand".

In 'Eye movements and visual perception' by Noton and Stark (1971) it was emphasized that subjects in similar environments and viewing similar scenes did not necessarily employ the same scan paths and that familiar learnt eye movements, such as reading, did not influence other scanning patterns. The authors referred specifically to the vertical format of the Chinese ideograms.

In general, references to research into scanning patterns did not provide significant evidence of pronounced directionality. However, it was noted that there was a difference between the pattern of eye movements when summarising the features of a pattern set close to the eyes and when scanning a wide field of view, when eye movements were not necessarily needed to enable a subject to recognise an object.

The wide variation in scanning patterns among subjects suggested that in the extra-vehicular environment the driver of a vehicle would not employ a predictable scanning pattern and therefore pronounced directionality was not necessarily a feature of the behaviour of the human component of a man/machine interface.
This lack of directionality is also considered in sub-section 3.3.11 (automobile factors).

A study was made of Kepes (1965) 'Structure in Art and Science' in order to search for additional side preference origins which might have arisen from factors similar to those discussed.

Kepes quoted Bertrand Russell as follows: "I believe that partly by means of the study of syntax, we can arrive at considerable knowledge concerning the structure of the world". Russell's observation referred to the thought processes which were based on the complex structure of a subject's language, which offered certain thought processes and denied others.

The foregoing, in the terms of the environmental psychologist, suggested that when searching for clues to man's behaviour in the control interface, account had to be taken of the possible influence of an operator's language. This suggested the intriguing possibility that studies of operator performance in a common interface be related to his language and particularly to the syntax of that language to see if there were any significant differences. This aspect might be examined in relation to the directionality of the language's writing form so that in the extreme we might expect a different conceptual behaviour and control behaviour in an interface between a European, an Arab and a Chinaman. We might go further and consider whether there were any discernible differences between a British and a German operator which reflected the difference in syntax of their two languages, which otherwise provided the same dextrad form.

A further study of Kepes, ibid, provided no significant factors relating to laterality from the perceptual processes used to study structures in art and science.

Although the dextrad tendencies used when conceptualising or executing the design of structures in art and science, as considered supra, were not
negated as evidence by the foregoing, nevertheless they could not be
said to support directly the general hypothesis of the dextrad influences.

1.10.3.
Directionality in man/machine interfaces.

A practical relationship between directionality and an operator's
behaviour in an interface was noted from research which had been con­
cerned with testing operators' reaction times to pointer divergencies
when using an instrumental interface consisting of a number of indicators.
The results indicated that operator performance was good with a dextrad,
superimposed lines arrangement, (as with the printed word) sic. Fig.
1.10.3(a), and better still with a dextrad rising line of indicators
sic. Fig. 1.10.3(b). (ref. Ergonomic Abstracts - Vol.2, 1970, No.56199).

\[ \begin{array}{cccc}
1 & 2 & 3 & 4 \\
4 & 5 & 6 & 1 \\
\end{array} \]

\[ \begin{array}{c}
\text{scan} \\
\end{array} \]

\[ \begin{array}{c}
\text{scan} \\
\end{array} \]

![Diagram a](image)

![Diagram b](image)

fig. 1.10.3.

1.10.4.
Left cortical dominance in visual perception.

Arnheim (1969) quoted Gaffron's (1950) reference to the dominance of
the left-brain cortex which contained the higher brain centres for speech,
writing and reading in a right-handed person. If that dominance applied
equally to the left-visual centre it meant that: "There exists a difference
in our awareness of visual data in favour of those which are perceived
within the right-visual field".
The foregoing comment by Mercedes Gaffron argued that vision to the right would be more articulate than to the left and, therefore, objects in the right-field would be more conspicuous. However, that did not correlate with those observations made by other researchers of a subject's attention to the left-visual field; as noted in subsection 1.10.1, and Kimura (1973) see 2.2.

The significance of Arnheim's observations to this research was as evidence of the possible influence of the dextrad writing form on human behaviour when conceptualising or operating a control interface. (see Section 4 for specific studies.)

1.10.5. Right and Left Fields of Visual Perception.

Part of the research which stemmed from studying the dextrad forms used for handwriting, the printed page and in art and structure in general was the construction of a model man/machine interface which was based on the designer's and operator's conceptual actions so as to represent the influences of innate and learnt dextrad preferences.

The hypothetical model was as fig. 1.10.5 and was intended to take in the principal perceptual factors referred to by Arnheim, Dean, Gaffron and Wolflflin.
In the above figure the scenario of perceptual actions was assumed to be as follows:

(a) Scan right-field and right side of interface.
(b) Scan indicators and controls from left-to-right.
(c) Coordinate right-hand with eyes and primary control which had been positioned by the designer to match the majority RHP population.
(d) Operator continues to monitor progress of vehicle relative to the optimum track by attention to the external visual field; interspersed with scanning of the control interface from left-to-right.

The foregoing hypothetical model and scenario was based on a dominant dextral scanning pattern with primary attention to visual data which appeared in the right-visual field. It provided a methodology for analysing a subject's perceptual behaviour in an interface but it was not a unique set of conditions, neither did it represent correctly all the evidence, including that of Arnheim and automobile driver research (sub-section 3.3.11). None of the evidence suggested that an operator was equally disposed to direct his attention to any particular part of the external visual field unless there were strong patterning and specific visual cues; such as signals.

The hypothetical model could not represent all the diverse perceptual situations met with by an operator. Neither could it represent the topography of any particular interface. It was recognised that the topography of an interface could impose rigorous perceptual scanning actions which required a definite directionality, but that directionality might have no relationship with innate or learnt behaviour from a subject's experience outside the vehicle operating environment.

An example of an interface which imposed a set of definite scanning actions which were not symmetrical about the operator's medial was the steam locomotive in which the driver's position was to one side of the
vehicle medial with the greater part of either the left or the right-
visual field obscured by the bulk of the machine. In addition to the
'skewed' visual field, the locomotive driver's attention had to be
directed to a particular sector of the forward view in order to detect
tlineside signals as early as possible. (ref. section 3.4).

Possibly the hypothetical model could be used to represent the loco-
motive situation but when related to the automobile and the aircraft there
was little relevance because of the great variety of visual perceptual
patterns and fields needed. The marine situation was considered separately
because of the complex relationship which might exist between right-side-
preference and the rules-of-the-road. In section 3.5 reference is made
to visual scanning patterns used by aircraft pilots; particularly as

1.10.6.
Head-inclination during problem solving.

Part of the research into perceptual behaviour involved reference to
Kinsbourne's (1972) inferences from head inclination during problem solving.

Kinsbourne observed a group of right-hand preferring subjects tackling
both verbal and spatial problems. Only a small number did not gaze around
while thinking about problems and of those who did the majority inclined
their heads to the right while sorting out verbal tasks and to the left
during spatial manipulations. Gazing during numerical problems was equally
distributed between left and right.

The foregoing was considered as another possible origin of side
preference and behaviour in a vehicle control interface. However the
research was not conclusive and therefore it was considered only as a
possible preliminary methodology and could not be applied directly to studies
of operator behaviour in a control interface.
If Kinsbourne's inferences were generally acceptable then in early and in simple man/machine interfaces, in which visualisation dominated the perceptual tasks, the operator's head would incline to the left. Further, when standing, if the operator's head inclined to the left then there might be a tendency to stand with the left leg forward.

As an example the following illustration, fig. 1.10.6, shows a right-hand preferring raft operator standing left-foot forward. Would the operator's head incline to the left? No conclusive evidence from studying illustrations was available from which to confirm the Kinsbourne theory.

A similar study was made of a horesman carrying a shield and lance and a coachman using a whip. Again the evidence was inconclusive.

Overall relating Kinsbourne's theory to specific man/machine interfaces was not a very fruitful exercise primarily because it had to be limited to those man/machine interfaces in which the operator was in a symmetrical situation or was constrained symmetrically to one position; as in an aircraft. In section 3.5. an important part of the causal chain which might have originated the aviation preference to turn left was the inclination of the pilot's head to the left. However, the link between Kinsbourne's theory and practice seemed tenuous.
Illustration of specific man/machine interface situations to which the Kinsbourne theory might apply.

Fig. 1.10.6.
1.10.7. Interim conclusion.

It was not found possible at this stage of the research to reach an interim conclusion that the visual perceptual scanning behaviour of an operator indicated any dominant influence from directionality induced by the dextrad writing and printing form. The evidence studied did not indicate that the dextrad scanning behaviour was a persistent feature of an operator's visual perceptual task when controlling a vehicle.
Summary

Handedness in relation to man/machine interfaces.

(1) Innate hand preference and side preference, reinforced during maturation by the subject's environment and by the social culture, provided a starting point when considering those man/machine interfaces in which 'conventional' or 'traditional' factors dominated the design processes.

(2) The literature of hand and side preference factors emphasized that in those M/M interfaces in which speed of operator response to instrumental stimuli was not a primary requirement and in which the interface DC relationships were simple, learning could overcome deficiencies in the ergonomics of the interface. The effects of fatigue, stress and disorientation on the operator had to be considered when studying the influence of hand and side preference factors on the efficiency of any interface. In other words, those early man/machine interfaces which exhibited, by present day standards, unacceptable ergonomics were used without difficulty because the operator was free from worry and the DC response rate was low so that the effects of stress and fatigue were not likely to arise.

(3) The relationship of learning in a DC task was considered important because evolution depended to a large extent on learning as a form of adaptation to situations. Dominant or traditional DC stereotypes in different types of vehicles acted as reinforcements to the right-hand-world. However, there were examples throughout the history of vehicles and craft of significant changes or reversals of established DC stereo-
In general, history, technology and culture did not provide specific examples of changes to DC stereotypes, which had led to operator errors, until the last 100 years. During the twentieth century the rapid increase in the literature relating to human factors and the design of man/machine interfaces as well as the analysis of incidents and accidents to vehicles and craft, provided examples of operator errors induced or contributed to by incompatible DC relationships or by 'reversed' stereotypes.

(4)
The influence of the dextrad writing form was one factor in the development of the right-hand-world and the evidence which was considered indicated some possible influence of the dextrad form on the positioning of controls and instruments in vehicles designed after about 1800. The Pilot Experiments described in Sect.4.App,A&B were directed at a quantitative analysis of the influence of the dextrad writing form.

(5)
The dextrad perceptual factors were examined as an extension of the influence of the dextrad writing form. It was found possible to construct a hypothetical series of operator's perceptual scanning actions related to the dextrad form but when they were applied to specific vehicles and operating environments there was little if any relevance.

(6)
Part of the field studies described in section 4 was based on the influence of the dextrad writing form as one factor in the conceptual behaviour of subjects when asked to decide on the topology of a set of controls.
Operator behaviour in the control interface and in the vehicle operating environment.

During the research into both human and vehicular factors it became necessary to look at both the behaviour of the operator as part of the man/machine interface and as part of the vehicle/environment interface.

1.12.1 The Vehicular environment.

In the vehicular environment it was conjectured that an operator's behaviour might be governed by interpersonal factors. Some of the many factors available from interpersonal behavioural research appeared relevant to the subject of the thesis, others were clearly not applicable; at least within the limitations of the research. Interpersonal factors were looked at therefore to determine their applicability on the basis that in a man/machine interface the operator's behaviour might contain traits which reflected his attitude to the machine; attitudes which might be expressed by using the methodology of interpersonal behaviour. To bridge the gap between ergonomics and interpersonal behaviour the concept of the quasi-vehicle environment was adopted: the pianoforte in a concert hall situation being the principal example used.

A particular study was made of Fisher (1970) 'Body Experience in Fantasy and Behaviour' to see if his research and conclusions provided additional evidence of behavioural factors in a man/machine interface. Fisher referred to human attitudes about body size, strength, sexual potency, cleanliness, agility and other body-image factors. Under the heading 'Right-Left Body Division', the general concept of the division of labour between left and right sides and the different symbolic values were reiterated. Reference was made to clinical observations in psychiatry and neurology of delusions and unusual ideas about comparative differences
in size between the left-body and the right-body. Subjects had: emphasized one side and denied the existence of the other; had labelled one side masculine and the other feminine. Overall, significant distinctions were made among the meanings assigned to the left and right sides. This was part of the right-left differences of cultures which adhered to beliefs and modes of expression which emphasized the contrast between left and right. Fisher proposed, ibid, p.373, that there was a body-image dimension based on symbology and culture which was significant.

The most applicable references in Fisher, ibid, were as follows:—

Behavioural variables denoted that organised experiences acquired structure and became vectors which exerted long-term directive effects. The body was a perceptual object from which a person could not escape. Fisher referred to the ways in which an individual distinguished his body from the rest of the world and how attention was distributed to the various body regions. Fisher discussed how characteristic modes of perceiving and appraising one's body were related to personality and how they influenced selective cognition and fantasy construction. Under the heading 'The Right-Left Body Division in Men and Sex Role' Fisher commented on the degree to which an individual focussed attention upon his right-side compared with the left-side of his body. This aspect was studied in order to check for possible relevance to operator behaviour in a control interface; either when conceptualising the design of the interface or when undertaking a control task. The Body Focus Questionnaire (BFQ) technique described by Fisher produced the result that the average tendency was for individuals to be more aware of their right-sides than the left.

Overall, the Fisher techniques did not appear to have direct relevance to the subject of the thesis other than to provide a possible area of future research into operator behaviour in a control interface. Fisher
made no direct references to man/machine interfaces and to any possible influences on an operator's behaviour which might derive from his concept of the body-image. Nevertheless, Fisher did provide this thesis with a possible methodology for studying an operator's behaviour and also for studying the conceptual behaviour of those who designed specific vehicle control positions. The body-image concept was used to reinforce the evidence used for analysing specific designer/operator behaviour in a control interface based on symbology and culture. Because it was not related directly to other research in ergonomics it was not used directly but limited to an introduction to the study of interpersonal behavioural factors in 1.12.2 et seq.

1.12.2

A method of analysing specific man/machine interfaces was constructed which would enable all the vehicle and extra-vehicle factors to be considered in relation to a set of standard concepts. The construct adopted was as follows: (fig.1.12.2).
AN OPERATOR’S BEHAVIOURAL CHARACTERISTICS IN THE MAN/MACHINE INTERFACE

The machine component of the M/M interface can consist of a contiguous arrangement of controls and indicators thus: 

Between the control face and the operator is an imaginary interface line or boundary which can be represented on a plan of the complete M/M relationship thus: 

The machine's topography can be represented thus: 

To the foregoing could be added a control interface which is an analogue of the machine's basic topography; thus:—

Operator's medial controls and instruments plane

Basal topographical matrix of machine

If the human component of the M/M interface is now added to the foregoing construct the following results:

an operator with a dissymmetrical 'envelope' or ergosphere

The above diagram represents an operator whose behavioural and physical characteristics are dissymmetrically arranged relative to the M/M interface. All the operator's perceptual and physical actions, which are deployed as part of the total control skill, are shown as being independent of the position and arrangement of the control levers, switches, etc and the indicators.

fig.1.12.2(a).
has characteristics which are not dissymmetrical; in other words the operator is 'skewed'.

In the following diagram, fig.1.12.2(b), the control face is shown, as in the previous diagram, as symmetrical about the operator's medial so that it represents a control interface which has been arranged without consideration of the operator's 'skewedness'. This arrangement in practice might be the result of mechanical and constructional features dominating the design decisions.

In contrast to the above diagram, the following illustrates a control arrangement which is displaced relative to the operator's medial so that the 'machine' component of the man/machine interface matches, to some extent, the 'skewed' face of the operator.

There are examples of man/machine interfaces in which the controls and instruments are skewed one way and the operator the other way.

Fig.1.12.2 (b).
The automobile provides a good example of a vehicle in which the operator is 'skewed' one way relative to his medial and the instruments and controls are 'skewed' the opposite way.

The left-hand pilot's seat and associated instruments and controls of an aircraft is an example of an interface which matches the operator's envelope. In contrast the right-hand pilot's seat and control interface does not match the dextrad majority of pilots. This is illustrated in Fig 3.5.7 p228 of this thesis.

Of all the vehicle types referred to in this thesis the helicopter provides one of the best examples of a control interface which was changed during the evolution of the helicopter from the left-side of the medial over to the right so that the operator's envelope and the mechanical requirements of the controls were better matched. See Section 3.5 1.12.3.

The Molar Environment and Human Lateral Asymmetry.

The environmental behavioural psychologists describe the physical world, as perceived by man, in terms of its whole being greater than the sum of its individually perceived parts. Asymmetrical man interfaces with the molar environment in a way which might modify the general theory of the environmentalists. One of the factors which might affect this behavioural set is the dextrad process which was considered in section 1.10 et seq. The possible significance of environmental behavioural studies, such as Craik (1970), to this research was in the differences which might exist between the vehicular and the extra-vehicular characteristics of operators.

If we consider the behavioural pattern of a significantly dextral person contemplating his environment can we hypothesise that his innate and learnt behaviour will be reflected by his resulting environmental concepts?
drawings. These were also applicable to the behaviour of a subject in the environment. One particular illustration emphasises the dextral concept: see Fig 1.12.3 on page 91.

![Diagram of striving forward heat stance]

During the research into behavioural characteristics in relation to man's environment it was noted that Kohler (1955) concluded that basically right-left relationships were not of a visual nature but were based on other behavioural relationships. This was part of Kohler's experiments in which subjects experienced optical distortion of the visual field.

1.12.4.
Interpersonal behaviour.

Evidence of handedness and side-preference in interpersonal behaviour was studied to see if it provided origins for human preferences when part of a man/machine interface.

Part of the study of interpersonal behavioural factors was concerned with the pattern formed by the subject's limbs, body attitude and the attitude of the head as well as all the other factors which, collectively, made up a specific posture.

A plan of an IPB interface posture was as follows:

![Diagram of IPB interface posture]

fig. 1.12.4(a) 0/M...operator's medial
For each possible interface, within the discernable classifications of conversation, combat, visual contact, bodily contact and through an interface made up of weapons or gaming equipment, a representative plan diagram was available with which to describe the symmetry or 'skewedness' of the interface.

Many of the man/machine interfaces to which this research referred were a combination of visual and tactual factors some of which might have had their origins in IPB. These were examined to see if they provided any links between human laterality and the design and evolution of vehicle control interfaces.

Consideration was given also to those man/machine interfaces which involved only visual inputs to the operator as well as to those for which the operator had no visual inputs from the extra-vehicular environment.
Some Types of IPB Interface—RHP Subjects

fig. 1.12.4(b)
Gestures and handedness

During the studies which were made of interpersonal behaviour consideration was given to gestures and handedness to see if there was any relevance to the evolution of interfaces.

This involved a general study of gestures related to hand and side-preferences. It was noted that some researchers into aspects of directionality had referred to Wolff (1943). Wolff considered the control of the right-side bodily actions by the left-cerebral hemisphere which represented to him the seat of all rational processes; while the right-hemisphere contributed control of the left-side and was the seat of the subconscious. Diagramatically Wolff's theory could be represented by fig. 1.12.5.

![Diagram of Wolff's theory](image)

Sorrell and Wolff argued causality of handedness factors but it was concluded that they started too near the top of the dependent chain of man/machine evolution to be directly applicable to this study other than when looking at interpersonal behavioural factors in a quasi-vehicle environment.

1.12.6.
Interpersonal behavioural factors.
Keyboard instruments.

Since the emergence of the keyboard instrument, as represented by the pianoforte, with the man/machine interface normal to the operator's medial, the dextrad order of discrete input controls has been adopted for other man/machine control interfaces. Fig.1.12.6(a).
In pianoforte and similar keyboard interfaces, the 'instrumental' interface is a combination of visual, aural and tactual perception. The input data, the music and, in one respect, the sound, are arranged in dextrad sequence which relates the left-hand of the control input to the lower symbols and tones with an ascending order towards the right-hand end of the keyboard. Fig 1.12.6(b).
Although there were many interpersonal behavioural factors present during the playing of a pianoforte most involved subtle techniques of skill which were not of any special significance to other man/machine interfaces which had similar keyboard inputs. However, the mechanism of the pianoforte, the dextrad low to high note order had shaped the instrument in such a way that for the best tonal and power effects it had to be positioned relative to the audience so that there was a right angle relationship in plan. That special spatial arrangement of instrument and audience was part of the total interpersonal relationship which existed between the performer and the audience. A relationship which included the instrument as part of both the man/machine interface and the audience/machine interface.

Contributing to that relationship were the dextrad visual perception factors as described, for example, by Arnheim (1969) pp.20-31. Part of the total influence on the performer's behaviour was the dextrad form of the music, which provided another factor to consider in the man/machine and audience/machine interfaces.
From the above fig. 1.12.6(c) can be discerned the spatial relationships which exist in the total IPB environment of pianist and audience. The dextrad keyboard, the audience to the right-side of the operator, the combination of IPB and the direction of the audience's perceptual processes, pianist-keyboard-instrument-sound, all in a clockwise, right-hand flow along the interface between audience and the man/machine. Again, those were factors relevant to Arnheim's (ibid) observation on perception in art.

The spatial arrangement considered, supra, is either coincidental with or derived from the Olympic circling in which the right-side of participants was presented to the audience when moving across their front. If the pianoforte were a vehicle and the pianist its driver, it would 'pass-in-review' in accordance with the traditions which stem collectively from the classifications Olympic and Sword which are basic to this thesis.

Summarising the pianoforte factors: no direct relationship or influence was claimed for interface design. It was studied only as one example of the way in which RHP and RSP factors might have influenced a quasi-vehicular M/M interface and how IPB factors could be studied as part of the overall consideration of M/M interfaces in which the machine replaced one of the two people of an IPB relationship.

1.12.7.
Social precedence as part of IPB.

Relative to the evolution of vehicle control position design was evidence of traditions and customs which prescribed the relative importance of positions. In the majority of human cultural traditions the position to the right as well as the right-hand took precedence over other positions. Such accepted conventions as the place of honour at the right side of a host were reflected by other social habits.
The right-precedence customs originated with man's terrestrial activities but were carried over to marine craft operation. On land, religious and court ceremonial established precise orders of spatial precedence. About the 15th century, when military operations in deep waters were taking an important part in international disputes, there started many of the present day naval and marine customs which stem from RHP and from right-side precedence. These are considered further in section 3.1.

As with most tradition and ceremonial there were sometimes rules and sometimes no rules to govern social behaviour.

The origin was often social convenience. For example, the sword-wearing customs. From convenience stemmed habit which, in turn, led to tradition and on to prescribed ceremonial. The history of vehicle controls, the conduct of ships and marine command practices are considered in detail in section 3.1 in which is outlined the evolutionary chain of traditions and rules extending from sword and social precedence to modern ship control interfaces.

1.12.8.
The Coach and Automobile and IPB

The traditions, long established, for the seating position of the person-in-control relative to others in a horse drawn vehicle were adopted without significant changes for the automobile. The horse-drawn coach
and the right-hand-drive automobile provided an example of a change in social custom, reversing a tradition, because of physical and mechanical convenience.

The armed man mounted his horse on the left side, engaged his opponent with the right hand and arm, saluted others with his right hand and conducted his vehicle, the horse, so that in conditions which dictated a choice to be made of on which side to pass an opposing rider, they passed right arm to right arm. The foregoing required no change to social behaviour until the coach and the automobile, with room to sit driver and others side-by-side, upset the social order. The 'inferior' servant now sat to the right of his master.

With the automobile there was no problem as long as the man who built it drove it and as long as the owner-driver drove from the right side with his fireman (chauffeur to his left or behind him. Only when the chauffeur became the man-in-control was the social order suspended. Barsley (ibid) illustrated an example of an important order for cars being lost because the potential buyer, an oil Sheik, was averse to riding to the left of an inferior (the driver who was on the right).


The majority of the factors considered which were based on the psychology of an operator's behaviour in both the vehicular and extra-vehicular environments were studied not as direct evidence in support of the thesis but as possible future areas of study.

The methodology for analysing man/machine interfaces (1.12.1) was applicable to all parts of the thesis but was included in this section in order to assist with the explanation of the relationship which was studied between the vehicular and extra-vehicular environments and the behavioural factors. In general, interpersonal behavioural factors were
not, within the limitations of the study, directly applicable to specific man/machine interfaces.

Gestures and handedness was an additional area of study the applicability of which was not directly apparent.

The hypothetical construct of the keyboard instrument as a quasi-vehicle was included in order to extend the scope of the research and to indicate its importance to the causal chain which extended from the Olympic circling directionality.

The socially dependent behavioural factors of 1.12.7 were included because they were considered to be key parts of the thesis as other links in the causal chain of vehicle evolution depended from them. 1.12.8 provided specific examples of the influence of social precedence.

Overall, section 1.12 was included to provide reference to the much wider operating environment which may have had an influence on the way in which human laterality had affected the design of man/machine interfaces.
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Section 2

INDEX:

2.1 Introduction

2.2 'Skewed' man *

2.3 'Skewed' man as one component of the man/machine interface.

* 'Skewed'man in the context of this thesis does not relate to the terminology of frequency distribution curves.
Section 2

2.1
Introduction

During the total research for this thesis the material gathered could be divided roughly between that which referred to human factors in isolation of vehicles and that which was relevant to specific transport factors and to specific types of transport. This section forms a link between the two groups of studies and therefore is based on the concept of 'skewed' man; that is man who has been influenced by the right-hand-world (RHW) of artifacts and who has, in turn, through his design decisions, influenced the RHW by his preference for the right-hand and the right-side.

2.2.
'Skewed' man

Handedness, as described in section 1, became a significant factor in the evolution of tools and other artifacts when the relationship between the 'grasping' and the 'working' surfaces needed conceptualising and when standardisation became an important requirement.

Bilateral symmetry became a feature of many artifacts and was possibly a reflection of man's own outwardly bilateral form. However, man made asymmetrical use of his limbs and often used pronounced and preferred directionality of movements and scanning so that his interface with artifacts and his environment and other men was 'skewed'. In other words, man did not always interface with his environment, both natural and contrived, in ways which produced symmetry of contact; even when the physiognomics were in balance with the interface.

Marion Kimura (1973) in her study of the asymmetry of the human brain considered the possibility that there may be some functional asymmetry between the hemispheres in primary processes as well as in the
more complex associative processes. Reference was made to the dominant role of the right-hemisphere in man's perception of his environment. Overall, Kimura provides a model of skewed man in which the different perceptual and cognitive functions together result in an asymmetrical human component in a man/machine interface. This asymmetry is significant in manual functions. For example, the ratio between left-hemispherical dominance and right-hemispherical dominance can be about 3:1 for a subject's free hand when making gestures during speech. Skilled manual functions differences observed during tests gave a ratio between left and right-hemisphere dominance of 1.13 : 1. With the relationship between manual and visual functions important in a man/machine interface, Kimura's test of visual perceptual performance, expressed as the ratio between left and right-hemispherical dominance, provided another measure of the extent to which the human component of a man/machine interface is skewed. Fig. 2.2.B.2 is based on the ratios published in Kimura (1973).

Specific to vehicle interfaces is the general finding that the identification of stereoscopic stimuli and the analysis of stimuli which give information about the location of objects in space is better performed by the right-hemisphere than the left, so that the majority of subjects in a control interface give better perceptual performances when the visual stimuli are presented to the left-visual field. This aspect of human behaviour is discussed in detail in 1.10.

Illustrations to 2.2

Fig 2.2.A shows a typical set of human lateral asymmetries. As noted in Section 1, handedness, as a quantitative factor, can be defined only in relation to a specific manual skill.

Fig 2.2.B1 is based on Kimura (1973) and illustrates the perceptual and cognitive asymmetries of the human component of a man/machine interface.
Fig 2.2.B2 is also based on Kimura (1973) and provides a more detailed analysis of the asymmetries of the various functions which together form the human component in an interface.

Fig 2.2.A
Visual spatial location
Identification of stereoscopic stimuli

Visual perception of words and letters

Aural perception of melody
Aural perception of human vocal stimuli

Aural perception of speech
Aural perception of 'nonsense' sounds

Speech functions
Manual control functions

Perception and conception of complex spatial, temporal and predictive functions
Perception and conception of environment

THE PERCEPTUAL AND COGNITIVE ASYMMETRIES
(Based on Kimura 1973)
FUNCTIONAL ASYMMETRIES of the cerebral hemispheres in normal, right-handed people are found in the auditory, visual and manual modalities. Test scores for the left and right sides were converted to ratios for comparison. The ratio for left-hemisphere dominance for perception of spoken words is 1.88 : 1, whereas the ratio for right-hemisphere dominance for melodies is 1.19 : 1. These ratios are not fixed values since they vary with the type of stimulus, the kind of response required and the difficulty of the task.
Skewed Man and the Right-hand-World

Fig 2.2.C is included to give a background construct for the specific man/machine interfaces studied in section 3. It is intended to show the three basic divisions in the history of the evolution of man and artifacts: one, before the emergence of the right-hand-world (RHW); two, the RHW, about 3000BC to the present; and three, the future world of technology.

Skewed man is shown in relationship to the RHW with the reinforcing factors represented by the loops of a closed system. One of the factors, grouped as ambidexterous artifacts, is shown as reinforcing a future world of technology in which the man/machine interface will increasingly be designed as a symmetrical arrangement of controls and instruments which can be operated with equal facility by either hand.

**SKewed MAN AND THE RIGHT-HAND-WORLD**

![Diagram of Skewed Man and the Right-hand-World](image-url)
Fig 2.2.D shows in greater detail the closed loops-of-influence used to describe the relationships that exist between man and the right-hand-world (RH\textsubscript{W}). The most important loops are those of positive and negative feedback from each new artifact; particularly from vehicles and systems in which there is a man/machine control interface.

It is postulated that if the controls and the rules of conduct of a vehicle system are predominantly left-handed (LH) or left-side preferring (LSP) then the total RH\textsubscript{W} influence on man's behaviour is reduced. If the controls and rules are predominantly RH or RSP then the total effect of the RH\textsubscript{W} is increased. If the controls and rules or the operating environment require no significant hand or side preferences then the total RH\textsubscript{W} influence is little affected.
Skewed man and the evolutionary system of loops of hand and side preferences.

Innate and learnt lateral human characteristics before the right-hand-world or uninfluenced by the right-hand-world.

**Human factors**
- Physiological
- Psychological

**Skewed man**

**LHP** Left **LSP** Left **RHP** Right **RSP** Right

**Minority**

- Circling circling

**RIGHT HAND WORLD (RHW)**

- Specific right-hand and -side artifacts, controls, vehicles, instruments and dextrad forms.

**Unhanded and ambidexterous artifacts**

- New artifacts, new vehicles, new man/machine interfaces; each of which is either:
  - LEFT, MEDIAL or RIGHT

**KEY**

- Feedback loops
  - reinforcing
  - reducing
  - little or no influence

- LHP - left-hand preference
- LSP - left-side preference
- RHP - right-hand preference
- RSP - right-side preference

Fig. 2.2.D
2.3 'Skewed' man as one component of the man/machine interface

In section 1, descriptions and research about human laterality in skill and control situations were reviewed. The innate and learnt laterality characteristics, with emphasis on hand and side preferences, were considered in non-vehicular control situations, in quasi-vehicular control situations and in the environment.

In section 3, this thesis considers specific vehicle control situations and the rules which evolved for their conduct in the operating environment. Control positions and rules of conduct evolved, in general, from a combination of two principal factors: (a) adaptation from preceding types of vehicle and (b) from convenience of operation.

During the discernable steps towards the definitive forms of vehicle and methods of operation 'skewed' man influenced to a greater or lesser degree, depending on the type of transport, the design decisions which had to be reached when arranging the control position and the placement of the controls and instruments. Lateral preferences have, through tradition, sometimes influenced the customs and rules relating to the conduct of a vehicle relative to its track and to other vehicles on or in the vicinity of that track; be it seaway, canal, path, railway, airway or road.

The degree to which human laterality, particularly that of the right-hand-preferring (RHP) majority population, influenced the evolution of vehicle shape and equipment and the way in which vehicles were conducted about their ways could not be expressed quantitatively because there was no suitable metric. To attempt to express the influence of RHP qualitatively it was necessary to examine each of the vehicle types considered in the thesis and attempt to determine which of the following were the origins of the principal control interface and vehicle conduct
factors considered: (a) Chance
(b) Human laterality
(c) Mechanical or operating convenience.
SECTION THREE
CONTROL EVOLUTION, RULES OF CONDUCT AND ASSOCIATED HUMAN FACTORS FOR SPECIFIC TYPES OF VEHICLES.

Sub sections:


B. Conflict of materials, control arrangements and human factors in general.

C. Methodology for section 3

3.1 Marine and river craft
3.2 Horse and animal transport
3.3 Automobiles and steerable land craft
3.4 Railways
3.5 Aircraft
3.6 Modern and future craft
3.1

**Marine and River Craft**

3.1.1 The evolution of water transport and operator's position

3.1.1a Chronology of marine and river craft factors

Illustrations to chronology Fig. 3.1.1.a

3.1.1b The operator's station and social position

3.1.2 Side preferences

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Illustration of right-side precedence and preference factors in warships

Fig. 3.1.8.e

3.1.9 Validity of assumptions
3.1.10 Summary and conclusions

Appendix A. Validity of assumptions
Introduction

A

Evolution of transport and associated human laterality in general.

Tracing back from the general to the particular was one way of determining the influence of hand- and side-preferences on the evolution and design of controls and control positions and on the evolution of rules for the conduct of vehicles and craft about their ways.

Starting with extant vehicle control arrangements and rules of conduct an examination was made of the extent to which human preferences had been the most likely origin of specific control position arrangements and of specific rules of conduct.

Marine and river craft and, to some extent, horse and animal transport provided a long causal chain of factors which stretched from about 5,000 years back. Hodges (1970) gave the year 1000BC as the approximate date when shipping became an established means of trading between centres of population. The year 1000BC marked the emergence of technology and the time when the wheel was revolutionising land transport and when sail-power had made long voyages a predictable venture. Other forms of vehicle had not had such long histories as the wheel/animal and sail/ship combinations. However, the newer forms adopted marine and equestrian terminology and equipment; and, sometimes, control practices. Both animal and sail powered transport systems remained in use in the modern world alongside alternative and often more efficient forms of transport.

Fig. 3A shows the basic construct used when studying the evolution of the different transport systems and their inter-relationships.
RAFT
Emerged at least 1 million years ago following chance observations of floating debris.

SLED
The sled emerged possibly about the same time as the raft and was derived from the application of natural material, such as a branch, to move loads too heavy for a man to carry.

ANIMAL POWER
Animal power applied after the period when man had learnt to domesticate animals [about 50 thousand years ago].

BOATS
Evolved from dugouts and from skin boats into reed and then planked hulls from about 5000BC.

PLANTS
Organised cultivation and animal husbandry started about 5000BC. The evolution of hoe into plough.

WHEEL
As progenitors of road transport, wheeled vehicles emerged sometime after 5000BC possibly about 3500BC.

SAIL POWER
Sail power as an adjunct to man-powered oars, emerged about 3500BC at the time of the first City-States.

STEAM POWER
Steam power applied to industry during the latter half of the 18th Century. Steam powered practicable vessels emerged during first two decades of 19th Century. Steam power applied to railway traction in the 1830s and to road vehicles.

STEAM POWER IN AGRICULTURAL MACHINERY c 1850

INTERNAL COMBUSTION ENGINE
Late 19th Century. Automobile emerged at end of 19th Century.

POWER HEAVIER THAN AIR MACHINES
First aircraft with engine and pilot 1903.

Evolution of modern transport:
Sail power replaced by steam power c 1830. Steam power replaced by other forms of power in ships during the 1930s.

Steam traction on railway superseded by other forms of power by 1960 in most parts of the world.

Steam power in agricultural machinery gradually superseded by other forms of power during the 20th Century and rare after c 1950.

Modern 'automobile' societies and behavioural factors.
Air transport part of a nation's social structure and economy.
Conflict of materials, control arrangements and human factors in general.

When machines and vehicles began to be used in significant numbers and there had to be some standardisation of design, a conflict arose between the limitations of the materials of construction, the arrangement of the components and the operating needs of the man-in-control. In general the research indicated that even when a designer had made an attempt to satisfy the human factors he was limited to observation of what others had done, to logical thinking and to humane motives because there was no literature, let alone ergonomics, from which he could determine the optimum design which would satisfy the conflicting requirements. With the exception of keyboard musical instruments, as quasi-vehicles, the application of ergonomics and the study of human laterality in the man/machine interface were of comparatively recent origin. 1900 was taken as a rough point in the history of man and machine at which serious attempts were made to consider human factors and the year 1940 the emergence of ergonomics; even though the word was not coined until 1949.

Aviation, which eventually required the extensive application of ergonomic studies in order to improve the efficiency of the interface and in-turn safety, was not the subject of human factors studies until after the first world war. In 1920 Flack read a paper to the Royal Aeronautical Society entitled 'The Human Machine in relation to Flying', but the relationship that the operation of an aircraft's controls had with the pilot's sensory inputs and the instrumental interface was not made the subject of serious study for another twenty years and such simple handedness concepts as 'throttle-side' and 'primary-control-hand-side' did not appear until 50 years after the birth of powered flight.

After about 20 years of the intensive application of ergonomics and human factors engineering to the design of vehicle control positions,
improvements tended to become marginal. Aviation, as an example, reached a time when progress in all its systems and operations were tending towards the margins of profitable return on capital. The aircraft instrument panel and the pilot's controls, for many years the subject of close study and improvements to improve efficiency and safety of use, reached a situation in which there were few 'ergonomic' changes. Only the 'unhanded' electronic (CRT) interface and the more extensive use of buttons in place of levers were changing the face of the flight deck.

C Methodology.

The separate evolutionary studies of the specific vehicle and craft types to which the thesis makes reference are, in general, confined to basic descriptions of the form, method of propulsion, and the track and operating environment. Where relevant, reference is made to any social behavioural factors which might have influenced the design of controls or the procedures for conducting a vehicle about its ways.

Analysis of vehicle, operator and environment for each specific type:

(a) the plan symmetry or otherwise of the vehicle about the usual axis parallel to the direction of motion;

(b) the symmetry or displacement of the operator's control position relative to the principal plan axis of the vehicle;

(c) the extent to which the operating environment of the vehicle imposed restrictions on any particular direction used for the conduct of the vehicle.
Procedure for examining specific control positions and procedures.

(a) Primary and secondary groups of controls were defined where possible.

(b) Without reference initially to human laterality, controls and other interface equipment were examined to determine the extent to which mechanical or other factors had influenced or constrained the design of the control position.

Possible influences which were considered as reasons or origins for the evolution of control practice.

(a) Innate human preferences
   - Traditional preferences
   - Religious preferences

(b) Human adaptability

(c) The influence of a hypothetical ambidexterous world in place of the right-hand-world as the basis of study.

(d) Social environment and interpersonal behavioural factors.*

* Social environment of operators

The social environment of the operator was considered from the point of view of the interpersonal behavioural factors within an operating crew and also from the point of view of the interaction between an operator and the vehicle operating environment with, in that situation, the operator/vehicle considered as a whole so that the 'behaviour' of the vehicle in the environment reflected the operator's behaviour. Any pronounced operator laterality might manifest itself in the lateral control of the vehicle.
3.1 Marine and River Craft

3.1.1 The evolution of water transport and operator's position

The evolution of artifacts in general included, by definition, the evolution of craft. As man evolved from the society and the artifacts of the Cro-Magnon period (250K-40K BC) he sought further ways of extending his influence on sources of food and materials. To do that he needed artifacts which would extend his range of action so that he was no longer limited to one day's pedestrian progress towards food or living sites.

In the established patterns of chance and conceptualised actions man, from observation of rivers carrying floating debris, contrived methods of supporting himself in the water. From observing that the bloated bodies of dead animals floated, man was able to contrive a raft of inflated animal skins. In those parts of the world where there was a plentiful supply of timber, rafts were built from branches.
Part One 10 000 BC to 1499

10 000 BC Evidence of first navigation at time when ocean levels rose.
ref: Clark and Piggott (1968)

7000 BC Paddle from that time found in England.
ref: literature in general

4000 BC Dugout boat of that time found at Pesse in Netherlands.
ref: literature in general

4000-2000 BC Mediterranean craft with central steering oar or
symmetrical arrangement of oars.
ref: Phillips-Birt (1971)

2000 BC Earliest known pictures of an Egyptian sailing craft; found on
a vase of that period.
ref: Landström (1969)

1000 BC Egyptian rowing galley with five steering oars.
ref: literature in general

1000 BC Egyptian vessels with medial steering oar.
ref: Landström (1969)

500 BC Greek or Cypriot craft with steering board on right with inboard
projecting steering arm.
ref: Landström (1969)

3rd Cent. Roman Corbita with steering board on both sides.
ref: Landström (1969)

3rd Cent. Judean ship with twin steering oars.
ref: Phillips-Birt (1971)

6th Cent. Combination of keel and side rudder made sail propulsion
practicable.
ref: Phillips-Birt (1971)

7th & 8th Cent. Nordic long-oar rudder, mounted usually on the right side.
ref: Landström (1969)

Pre 12th Cent. Many illustrations show two steering boards; one on each quarter.
ref: literature in general

12th Cent. Medial rudder developed in the Occident.
ref: Mariners Mirror No26 pl11
ref: Phillips-Birt (1971)

Illustration of medial rudder on GOTLAND ship shows
tiller passing to right of the stern post.
ref: Landström (1969)

14th Cent. Twin side-rudders still in use on a Mediterranean ship.
ref: Phillips-Birt (1971)
Part Two 1500–1899

c1500 Whipstaff developed to give helmsman better view of sails in large ships. ref: literature in general.
1597 Dutch East Indiaman: equipped with whipstaff and window at helmsman's position. ref: Wilkinson (1971)
1700 Windlass in place of tiller and whipstaff arrangement tried in British warships. ref: literature in general.
1705–12 Period in which steering wheel came into use in the larger types of ships. ref: literature in general
1783 First steam craft: the Pyroscaphe ref: Rowland (1970)
1794 Master-at-Arms' hammock on starboard side of 24-gun ship. ref: Steel (1800)
c1800 HMS Victory: officers' lavatory on port gallery; Lord Nelson's favourite seat in window of stern cabin was on starboard side. ref: Steel (1800)
1863 International consideration given to the establishment of a rule-of-road at sea which would accommodate both sail and steamships. ref: literature in general.
1863 Ship the Wild Deer had Master's cabin on portside instead of, as was customary, on the starboard side. ref: Hogben (1972).

Part Three 1900–1972

c1900 Numbering of lifeboats on passenger ships so that No 1 is on the starboard side forward followed by odd numbers and with even numbers on portside starting with No 2. ref: Hogben (1972)
c1900 Steam trawlers with working gear on right. ref: literature in general and models.
c1900 Royal Navy ships, in column line-ahead, kept to left when meeting opposing traffic. ref: Henderson (1972)
1904 HMS Swiftsure and Triumph: sheet anchor to port instead of to starboard, as was customary, in Royal Navy. ref: Parkes (1970) p439
1909 HMS Glasgow: wheel on forebridge to right of binnacle. ref: Science Museum model.

continued/
1911 RMS Monarch: wheel on forebridge to right of binnacle.
ref: Science Museum model.

c1911 United States Navy custom of designating the forward starboard engine room control platform as the principal engine control position for a ship.
ref: Beech (1967)

c1914 German and US Navies carried sheet anchors on port bow not, as Royal Navy, on starboard bow.
ref: Phillips-Hornby (1972)

1913 IBIS Dauntless: wheel and telegraphs to right of bridge medial.
ref: Imperial War Museum model.

1956 TS Zenatin: aft steering position equipment on starboard quarter abaft the deck house.
ref: Science Museum model.

c1958 Boating Industry Association USA: recommended that driver's position be to the right-side of control position.
ref: BIA circular.

c1972 Trawlers involved in Cod War between Britain and Iceland streamed their trawls from the portside instead of from the usual starboard side so as to confuse trawl-cutting gunboats.
ref: BBC TV feature film.

1972 NNS Dorina: helmsman's control console on left, command console on right of bridge medial.

1972 LCS Iroquois and class: command console to right of other control positions in Combat Information Centre.
ref: jnl. Navy Intl.,72 p27
Mediterranean multiple steering oar arrangement c 2000BC to 15th Cent.

Northern single steering-oar tradition. Gokstad ship c 500AD

Crooked stern junk of Fouchou.

Illustrations to Chronology
Fig 3.1.1.a
3.1.1.b
The operator's station and social position.

Compared with road vehicles, marine and riverine craft design and operation in general appeared to have been far less influenced by an operator's laterality characteristics.

The operator's station was not usually confined to one position relative to the vehicle medial by social precedence. On the open sea the freedom of manoeuvre and the variables of wind and sea conditions resulted in a random pattern of vehicle behaviour in the operating environment. At the same time the vehicle operator either controlled from a position on the medial or from either side without limitations from social factors. At this point it is necessary to reiterate the difference which could exist between the operator of the vehicle and the person in command.

For the first 3000 years or more of marine and riverine navigation the special skill of the seaman placed him in a social position between those of slave and master. Provided the steersman was in an operating environment of short time prediction of events then he was able both to steer and command the vessel. When it became necessary to predict events a longer time ahead then the commercial, tactical and strategic needs were met by employing a master who did not necessarily handle the controls. Eventually the 'sailing' master became subordinate to the military commander at sea.

In sailing ships the master would stand to one side of the vessel's medial in order to get a good view of the set of the sails or navigational features. If the master were not constrained to one side because of the handling characteristics of the ship and the way in which the sails were set then he might, under the influence of social precedence, stand to the right of the medial. At the same time the helmsman, the 'operator',
was confined to a position close to the steering wheel or tiller which was on the medial of the vessel. However, the helmsman might stand to one side of the wheel in order to watch the set of the sails and therefore his position, as with that of the master, depended relative to the medial on the side to which the ship was tacking. Hand and side-preferences were not then significant influences on the design of a ship's operating equipment or on the way in which it was handled on the open sea.

Marine and riverine craft can be divided approximately into those in which the operator is constrained by the design to one location relative to the vehicle medial and those in which the operator is free to move from one side to the other. When the operator is constrained to one position, particularly in small craft, hand-preference and bilateral asymmetry of control equipment provide one set of interface factors often different from those met with when the operator is free to move from one side to the other.

In other forms of transport there was a clearly definable topographical relationship between primary and secondary controls. In marine and riverine craft, primary controls, such as steering and power, might be in locations separate from the ergosphere of one operator. Secondary controls were not always definable in the terms of road, rail and aviation vehicles and the comparatively large size of a ship compared with the ergosphere of its operator prevented the establishment of a stereotype man/machine interface in which the primary and secondary controls could be related directly to human laterality.
3.1.2

Side Preferences

3.1.2.a.

Dominant right-side position

The importance of the steering-oar at the starboard quarter (right) to the subsequent evolution of steering gear was clearly recorded by the histories which were researched. The number of exceptions to the apparent rule was small compared with the large number of craft of all types that had been built in the last 12,000 years.

Origin of right-hand and -side preference in craft control

The search for the answer to the key question 'Why was the right hand and side preferred?' was based on two basic possibilities. One, that the steersmen during the evolutionary period of water-borne craft on open waters adopted a stance and method of holding the steering artifact which matched the operating environment or, two they adopted steering practices which matched their laterality.

3.1.2.b.

Human behaviour and the steering artifact on the right.

Consideration was given to a hypothesis related to single steering artifact arrangements as follows:

That the right arm, in the majority of subjects was the stronger of the two arms and therefore was able to apply greater downward push when propelling a vessel by means of a pole. That the left arm, being the weaker of the two, was preferred as the arm for pulling downward on a pole during the thrusting stroke of action. Thus:
That the pole was the progenitor of the steering artifact and therefore when man came to use a long sweep or oar to steer with he was already accustomed to using it on his right. Thus:

If it were necessary to use both hands on the steering artifact then man was accustomed, from using other artifacts, to adopt a stance which was thus:
The foregoing hypothesis was based on a simplified assessment of man's actions when using pole-like artifacts and the relevance to steering devices was possibly one of convenience rather than of fundamental importance. However, the use of the simplified analysis of human stance and hand positions served to illustrate one hypothetical way in which the steering artifact had evolved and the way in which human lateral preferences had influenced those actions. It was recognised that for each of the 'right hand preference' stances there was a left hand stance and therefore only a dominant RHP factor could have made any significant contribution to the way in which the right-side steering artifact had evolved. With the general basis of the complete thesis one of a majority population of RHPs then the foregoing construction was considered admissible.

The correspondence between right-hand and left-hand stances when holding a pole were illustrated as follows:

Fig. 5.1.2e 1-4
3.1.2.c

Leg preference factors

When man first ventured onto the water on a crude raft or inflated skin it was likely that he used his legs as well as his arms for propulsion and for steering, and in some parts of the world the foot was still used for manipulating a paddle. Therefore, the research had to consider leg-preference factors as well as those of hand- and side-preference.

No evidence was found of significant leg-preference when using the limb as a steering oar either in extant populations or from studies of early man. It was considered unlikely, in the light of subsequent human control action studies of the use of the legs, that one was preferred to the other. The differences noted by researchers between the two legs in co-ordinated control and strength were marginal.

The leg preferences discerned by modern researchers, such as Clark (1957) were concerned primarily with a subject's preference for a particular limb to be used in an eye/limb co-ordinating task: such as kicking a ball accurately. The relatively crude co-ordination task of using a limb as a steering-oar was unlikely to have been influenced significantly in choice between left and right limb by side-preference or by leg preference factors which were present for more skilled tasks.

As long as man lay or sat on his craft and used his limbs for steering as well as propulsion it was considered that limb preference characteristics were not significant. It was not until paddles, poles and steering-oars came into use, from about 3000 BC onwards, that hand- and side-preferences exerted an influence on the design of craft and the artifacts evolved for their control.
3.1.3.
Specific lateral factors and alternative influences

3.1.3.a.
Introduction

The research showed that it was only a comparatively short span of time (about 3000 years) from the evolution of sea-going craft, with a steering oar to one side, until it was an established custom to put the principal steering artifacts on the starboard quarter.

The research attempted to find reasons other than right-hand and side-preferences (RHP and RSP) for what appeared to be a universal custom or tradition. It was postulated that some isolated communities might have evolved craft with bilateral asymmetrical shapes and with the steering artifact on one side because of environmental constraints on manoeuvring. At the same time, the factor of chance had to be allowed for on the basis that if there had been no pronounced hand- or side-preferences then a prototype steering artifact was just as likely to have been placed on the left as on the right.

The following specific examples were studied: environmental influences; Polynesian outrigger craft; twisted stern craft of China; the Venetian gondola; the sheet anchor; fishing gear; Chinese and Japanese inshore craft.

3.1.3.b
Environmental influences.

A premise that the maritime operating environment might have influenced craft design in favour of the right-side did not appear supportable by fact. This was an argument which ignored the factor of chance which, had the influence been significant, would have resulted in about half the world's craft with the steering artifact on the left with the other half with the steering on the right. With the exception of a few isolated
examples, with oars or rudders at both quarters, the records endorsed the evidence of right-side preference. Even some of the exceptions which were noted, those with single steering devices on the left, were suspect as evidence because they might have been incorrectly depicted by the artist so that the steering artifact was drawn on the side of the vessel which was presented to the viewer.

The chance topography of land and seas was one in which the steersman would be presented with an environment of constantly changing relationships between his vessel and the topographical features. Furthermore, he was just as likely to make as many outward voyages as inward so that he would become accustomed to an operating environment having navigational features in many different positions relative to the ship.

Consideration was given to the argument that the general wind direction imposed a set of operating conditions which might have influenced the helmsman's preferred side. Although there were some records which suggested that ship handling in particular parts of the world had been influenced by the direction of the prevailing wind and tide none was supportable by fact. (see also reference to sheet anchor practice.)

3.1.3.c
Polynesian outrigger craft.

Many of the Polynesian outrigger canoes which were studied had the outrigger on the left-side so that the paddles tended to be used on the right side. A related study showed that, in general, the principal paddler in a crew used his paddle on the right side of the craft. However, a study of the operating environment and the literature of the Polynesian canoe fleets did not reveal any dominating conditions or traditional customs, other than right-hand-preference, which might have influenced the choice of which was to be the 'outrigger' side and which
The conclusion reached was that the Polynesians were just as right-hand preferring as other ethnic groups so that using the paddle to the right-side of a canoe was an innate characteristic which had been reinforced by the Polynesian equivalent of the right-hand-world of the higher technology nations. The extensive studies of the maritime peoples of the South Pacific by Heyerdhal (1950) supported the evidence of their dextrality.

3.1.3.d
Twisted-stern craft of China

Craft which were operated on the swiftly flowing and tortuous rivers of China were sometimes designed with bilateral asymmetry which possibly reflected the difference between the downstream and upstream operating conditions or the influence of human laterality. Most likely the two factors, environment and human laterality, combined in the evolution of the design. These craft, according to Worcester (1966) p.122 et seq, were steered by one medial sweep and another on the right quarter and sometimes a third on the right bow. In other words, three right-hand-preferring operators controlled the craft and the twisted stern, as illustrated in Fig. 1.1.1.b, was the result of human laterality and the difference between the downstream and upstream steering problems. Worcester, the acknowledged authority on Chinese river craft practice, did not pontificate on which of the influences was the greater.

3.1.3.e.
Venetian gondola

A Venetian gondolier stood on the left-side of his craft operating the single oar to his right. That was included as an example of human lateral preference influencing the design of a vessel with the result that there was a 'working' side (right) and a 'docking' side (left). The hull form of the gondola was asymmetrical to compensate for the use of an
3.1.3.f.
Sheet anchor position.

An example of apparent handedness.

The sheet anchors of the two largest fleets at the time of the Napoleonic wars, the British and the French, were carried on the starboard bow of the warships. That tradition persisted in modern times. The origin of the tradition could not be verified. All that was available as evidence were reports that the British preference for carrying the sheet (spare) anchor on the starboard bow, so that there were two anchors on the right and one on the left, derived from a combination of wind, tide and land direction such that an additional or emergency anchor could be used most effectively if carried on the right-hand side of a vessel. Right-hand-preference as an origin fitted the argument had the British practice been considered in isolation of what other navies did in the same waters and at different periods in history. For example, the German Navy at its peak in 1914 standardised the sheet anchor position on the left bow as did the United States Navy. Therefore the facts neither supported the RHP theory nor the environmental conditions theory.

An indirect reference to the use of anchors on a particular side was Brown (1942), p.314, who described the 'working' anchor in the Northern Hemisphere as that on the left-bow of a ship. In the Northern Hemisphere wind and sea conditions which might require the use of a second anchor occurred when the wind veered (clockwise). The geometry of the anchor cables was simplified if the left-hand anchor was always used first.
3.1.3.g.
Right-side preference for working gear

Starting with the basic port or 'dockside' and starboard 'operating' side it was noted that those definitions and uses of the two sides of a vessel had influenced subsequent control and equipment practices.

As an example of the foregoing, drifters and trawlers had the net working gear, such as the gallows (a hooped shape frame), on the right hand side of the ship which was the 'working' side.※

An example of a stereotype arrangement being used to confuse a situation came about when trawlers fishing inside the limit set by Iceland during the 1972/3 'codwar', started to trawl from the left-side instead of from the usual right-side. That was done to confuse the patrol ships which were trying to cut the trawl cables by steaming across the starboard quarter of a trawler.

A contrary example was found in the one time preference Japanese fishermen had of operating a single oar or scull over the port quarter of a craft. They also preferred to handle the nets on that side. Similarly, from observation of a film dealing with the life and work of the fishermen of the South China Seas, there is to this day a preference for operating a scull over the port quarter so that the operator stands facing the left side of the vessel. This stance is the mirror image of that shown in Fig 3.1.2.b.3 page

The origin of the preference for handling fishing gear over the starboard side of a ship may not entirely have arisen from right-side preference; as described supra. The general practice of using a right-hand screw propeller, which influenced the way in which a ship responded to the rudder, may have been of equal importance as an origin.

(A right-hand screw propeller results in handling characteristics in which it is easier to make turns to the right with the result that fishermen prefer to keep the wind, waves and nets on that side when hauling in.)
3.1.4

Side Precedence Factors

3.1.4.a

Right-side precedence

The origin of right-side precedence (RSP) at sea might have been with the social and military precedence which was related to the pecking order: as evidenced by court, temple and military ceremonies which prescribed the spatial relationships of people in a group for which the diagram (below) was a simplified example:

![Diagram](image)

(The numbers represent seniority with 1. the most important and X represents a person who has a special relationship to 1. outside the pecking order.)

From the foregoing might have stemmed the naval customs of:

- the senior officer's stand or seat to the right of the control position medial;
- the demarcation of the quarterdeck so as to reserve the starboard side for the use of the senior officers;
- the use of the starboard gangway or entrance port by officers whenever practicable.

3.1.4.b

Evidence in support of hypothetical causal chain

The more the influence of right-side-preference on marine customs and practices was researched the greater the awareness of the extent of that influence. At the same time, it was realised that much of the evidence was unsupported by fact. There were many interesting anecdotes and references to side-precedence and -preference but no authority was prepared to make positive statements about their origins. All that could be concluded was that there had been a tendency, whenever there had been an equal choice between left and right, to designate by habit
or tradition the right-hand position as superior to the left.

At the time of the Dutch Wars in the 17th century, when many practices and traditions were established, it was possible that the military custom of the senior officer standing on the field of battle with his subordinates to his left might have been applied also when commanding from the quarterdeck of a ship. Hogben (1972) proposed that the origin of right side precedence was earlier in time.

Henderson (1972) pointed out that in the Royal Navy columns of ships kept to port when meeting opposing traffic which might indicate that the preference for the right-side position was an influence with the result that ship's commanders preferred to pass 'superior' side to 'superior' side. However, this naval practice conflicted with the Rules for Preventing Collisions at Sea concerning which side vessels should pass: opposing vessels must alter course to the right. Without positive evidence the foregoing causal chain was only conjecture. However, it was significant that over two hundred years after the rise of naval power and traditions, the vestigial quarterdeck of a Royal Navy ship would be demarcated so that the senior officers had the starboard side reserved to their use.

3.1.4.c
Right of medial position and rule-of-road.

The research was extended to look at the practice of the officer-of-the-watch taking position to the right of the control position medial. Observation, literature and discussions with naval historians supported the fact that the Captain or his representative (Officer-of-the-watch) stood or sat in the right-forward corner of the principal control position (compass platform) in a warship. However, it had to be emphasised that the right-side position was not unvarying. If the tactical or ship control situation required access to another vantage
point or to another part of the control interface then the apparent custom was abandoned.

The right-side preference factor had to be related to the rule-of-the-road which, essentially, required one ship (the burdened) to give way to another (the privileged). One of the more dangerous situations arising between two conflicting ships was that in which one ship found another approaching in the arc which extended from ahead to about 3 o'clock. See fig. 3.1.4.c.

![Diagram](image)

The officer of the burdened ship (A) was required to control his ship in such a way as to avoid collision with (B) the privileged ship.

Fig. 3.1.4.c.

The question for which an answer was sought was: Did the practice of the ship's commander keeping watch from the right of the medial dictate the rule-of-the-road or the other way about? If the right-side preference origin was unacceptable then it was introduction of the rule, in the middle of the 19th century, which resulted in the watch-keeper tending to stand on the starboard side of the control position as that was the side from which would appear conflicting vessels to which he had to give way. This was reflected by the Boating Industry Association U.S.A. recommendation that the driving position for motor-boats be to the right of the medial.
3.1.4.d
Visual perceptual preferences.

As with other forms of transport, the visual perceptual factors were considered to see if there were any differences between perception in the left and the right visual fields. Correspondence in the Mariners Mirror did not illicit any substantial references to left and right field perceptual differences other than from Chowdahary-Best (1972) who referred to the use of the 'master-eye' and based his comment on the fact that the 'master-eye' was the right-eye in 64% of adults. He suggested that because objects presented to the right-side of an observer's visual field were recognised more easily than those presented to the left-field then the marine rule-of-the-road, concerning which of two vessels had the right-of-way, was an example of a physiological factor influencing rule making. This comment matched with Gaffron's (1950) proposal that visual data in the right-field was favoured. In general, the evidence was inconclusive even though the practices appeared to fit conveniently into a causal chain of evolution.
Nomenclature based on right-side precedence

Part of the evidence was based on the numbering of ship's lifeboats and compartments so that No. 1 was on the right, forward, with odd numbers extending aft. In some ships compartments were numbered with the odd numbers to starboard. In the United States Navy, right-side precedence was emphasized by the designation of the forward starboard engine room as the 'lead', i.e. senior or principal control station. A similar designation was used in some British warships. It was noted that the Italian cruiser the Vittorio Veneto had the helicopter landing deck positions marked with odd numbers to the right and even to the left.

Whistle codes, to indicate the intentions of a ship's commander, specify one blast for a turn to the right, two for a turn to the left.

In some respects this nautical terminology was reflected by Fritsch (1968) p.16 in which he referred to: "Odd numbers: male, light and motion, straight, good and right. Even numbers: unlimited, mary, female, darkness and evil".
3.1.6
Asymmetry of Controls in Merchant Ships

The research considered the disposition of the controls on the bridges of merchant ships at the start of the 20th century. Wilkinson (1971) had given examples of the type and arrangement on some typical ships' bridges. Of importance to the research was the way in which in the RIMS Dufferin of 1905 the docking telegraph was on the port side of the bridge and the anchor telegraph was on the starboard side. It was considered unlikely that there had been strong mechanical reasons for the choice because the connecting systems could have been placed to either side of the ship with equal facility. What the facts did suggest was than when the designer of the ship came to choose the positions either lateral preference or tradition had governed his decision. The TSS Orama of 1924 had a similar arrangement of the docking and anchor telegraphs.
3.1.7
Control Stereotypes

The ship's wheel and tiller were considered in relation to expected or reversed display/control (D/C) stereotypes using the references in section 1.3 as a basis.

3.1.7.a
The ship's tiller

Research was made into the evolution of the centrally hung (medial) rudder with tiller extending forward to the helmsman's position.

The precursors of the rudder/tiller arrangement were all simple mechanical levers, the movement of which gave an expected example of control action. Bow mounted steering oars or sweeps (ref. Worcester and Needham, ibid) also gave expected control movement even though the movements were opposite in direction for a given effect to that of a stern tiller.

In general, expected relationships predominated and no examples of 'reversed' tillers were found.

3.1.7.b
The ship's wheel

The ship's wheel was a right-for-right stereotype even though it had been evolved in a period of technological evolution well before such precise definitions had been applied.

The arrangement of the ropes from the head of the tiller to the windlass of the wheel presented the naval architects of the first few years of the 18th century with a simple mechanical choice involving nothing more than the direction around which the tiller ropes would be laid on the windlass drum. When the wheel replaced the whipstaff, c 1705, it was as a windlass with ropes from the tiller passing athwartships, around blocks and back to the windlass drum set on the ship's
The tiller ropes could equally well have been passed anti-clockwise, looking forward, as clockwise with the result that the modern ship's wheel would have been part of contrary direction control and, therefore, not an expected D/C relationship.

The reason for passing the tiller ropes clockwise on the windlass might have been inspired by those human preferences which favoured circling to the right which in the superstitious society of seamen might have been a strong influence. Alternatively, the 'mechanical' requirements relating to the way in which ropes had to be coiled may have been the origin of the stereotype.

The research found no positive evidence in support of any particular reason for the foregoing.

Had the ship's wheel evolved with a wheel 'input' rotation opposite to that which was adopted then, as a stereotype, not only for ships but for other forms of transport, one of the most important man/machine interface factors would have been very different. The argument might have been: As the tiller head moved opposite to the direction in which the ship's head moved then the upper part of the wheel rim and its spokes should have moved in a way which replicated the tiller movement. Although the foregoing did not take place and therefore was of little consequence, nevertheless it provided a basic analysis of the origin for the modern control stereotype.

The explanation for the origin of the wheel stereotype was not with the movement of the tiller but with the movement of the whipstaff. The whipstaff head, see Fig. 3.1.7.1, was moved towards the direction of the desired turn thereby displacing the tiller in the other direction. The upper spokes of the wheel, therefore, replicated the direction of movement of the whipstaff.
The direction of motion as a simple lever in the causal control chain could be easily understood. It was possible that there were helmsmen who did not grasp the relationship but as the consequences of error were usually quickly apparent then the one-trial-error situation applied.

3.1.7.c
Hand preference and the ship's wheel

Once the wheel had been established on the medial it was concluded that any question of hand-preference was eliminated. Some nautical writers had asked: To which side of the wheel did the helmsman stand? The question was considered too simple for the complex relationships which existed in practice. For example, it was noted that a sailing ship was rarely on an even keel, the wind direction relative to the sails and the setting of the sails often dictated the side to which the helmsman should stand and there was a 'weather' side and a 'lee' side both of which governed to some degree the preferred positions of the master and the helmsman. In general, it was noted that the 'control' crew members used the weather side as that gave the best sight of the way in which the sails were performing.
3.1.8
19th Century Steamships

3.1.8.a.
Introduction.

The steamship required eventually a new set of control equipment and control scenarios different in many ways from those of the sailing ship.

Unlike the steam locomotive, which is dealt with in section 3.4, the steamship control position was not deliberately contrived. What had gone before dictated to a large degree the position of the controls. The early steam vessels were, essentially, only sailing ships to which had been added steam power. The engine and the paddles were midway along the hull. The controlling engineer's station was at the engines so that he was removed by half the length of the ship from the master who conned (controlled), as in a sailing ship, from the stern part of the ship; sometimes adjacent to the wheel or from some other point of vantage. Orders to the engineer were transmitted verbally or by knocking on the deck. In the early years of steam at sea and for the following two or three decades, there were no instruments available to the captain from which he could ascertain the setting of the engines.

3.1.8.b
The control position

By 1845 the paddle and screw ships were being equipped with a control bridge amidships from which the master could con his ship. However, engine orders were still being passed verbally by shouting down the engine-room hatch or by knocking on the deck. In the Victorian novel, 'Valentine Vox, there was one of the earliest fictional accounts of the misinterpretation of orders and a deliberately induced state of oscillation in a control loop, when the principal character used his ventriloqual
skill to change the Captain's orders and the Engineer's response.

3.1.8.c
Control loops, orders and definitions

From the aspect of ergonomics, the verbal control loop, including the use of voice pipes, of the early steamships, was not necessarily inefficient. The speed of vessel response to an engine order was long compared with the time taken to transmit the order. Apart from the elimination of distortion of the verbal control link, an engine-telegraph did not completely improve the control loop.

The slow responding control loop tended to disguise handedness factors as there was usually time for an operator to adapt to the control arrangement; in other words, a one-trial situation.

A particular aspect of handedness in ship control which was studied concerned helm orders. Until 1930 helm orders in English referred to the movement of the tiller and not to the movement of the rudder. For example, in sailing ships, steering orders related to the side of the ship exposed to the wind. To turn the ship's head away from the wind the order would be given "Put the helm up". As was observed, those orders were not given as rudder corrections relative to the left- and right-sides of the vessel. However, when steamships came to the scene the tradition of sail persisted and helm orders used reverse terminology, i.e. "Port-the-helm" for a turn to starboard.

3.1.8.d
Right-hand screw propellers

It was noted that the most usual direction of rotation of a ship's propeller was clockwise when looking forward. This particular direction of rotation produced a difference in the way in which a vessel handled between turning to the left or to the right when coming alongside a wharf. It also influenced the choice of side for handling fishing gear, as described in 3.1.3.g.
This was an example of a mechanical factor which could affect the way in which a ship was handled and which might in some circumstances of wind and tide and local conditions influence a master's decision between action to the left or to the right.

3.1.8.e
The control position in warships

Until recent times warships of the Royal Navy had conning positions separate from the wheel and the engine-room telegraphs and the person-in-command continued to rely upon the voice pipes for the transmission of helm and engine orders with the result that the medial of the control position was defined by the compass binnacle and by a primary control wheel or lever; as in many other forms of vehicle.

Fig. 3.1.8.e summarises the principal factors studied relating to the control of warships. The aircraft carrier with the control position to the right of the medial is an example of a traditional preference for the right-side in conjunction with a preference from another form of transport, aviation left-hand circuit see section 3.5., establishing a stereotype position.
Illustration of right-side precedence and preference factors in warships.

Right-side social precedence on land
↓
Right-side precedence at sea
↓
Naval quarterdeck
↓
Naval control position
↓
Senior officer to right of control position medial
↓
Engine control positions in United States Navy vessels, designated so that the senior position was to the right.

Rule-of-road
(in general a ship gave way to one on its right side)

Aircraft carrier control position to the right of the medial

Aviation left-hand circuit

Fig. 3.1.8.e.
3.1.9
Validity of assumptions

The validity of the assumptions and the hypothetical causal chain concerning lateral precedence and preference in marine and riparian craft were tested by submitting a study of the relevant factors to the Royal Institute of Navigation, ref: Coombs (1972) and a communication to the journal Mariner's Mirror, ref: Coombs (1972).

The comments received provided additional evidence in support of the general conclusions. These comments are given in Appendix A to this section.
3.1.10

Summary and conclusions.

Evolutionary Diagram of left, medial and right factors in marine and riverine craft control positions, control equipment and conduct practices. Fig 2.1.1a.

Of 31 items of evidence examined 16 indicated a preference for positions or operations to the right of the ship's or track medial, and only 3 were to the left with the remainder representing symmetrical or medial arrangements of equipment or practices.

The following items of evidence were described in detail in 3.1.1.a.

<table>
<thead>
<tr>
<th>Event Date</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>c1972</td>
<td>Iroquois class ships with command console on right</td>
</tr>
<tr>
<td></td>
<td>NNS Dorina with command console on right</td>
</tr>
<tr>
<td>c1972</td>
<td>Trawlers with working gear on right</td>
</tr>
<tr>
<td>c1958</td>
<td>Boating Industry recommendation in USA that driver's position be to right of medial</td>
</tr>
<tr>
<td>c.1956</td>
<td>Example of control position offset to right</td>
</tr>
<tr>
<td>c1918</td>
<td>Example of wheel and telegraph to right</td>
</tr>
<tr>
<td>c1910</td>
<td>USN practice of superior positions on right</td>
</tr>
<tr>
<td>c1900</td>
<td>Sheet anchors to right in Royal Navy</td>
</tr>
<tr>
<td>c1900</td>
<td>Steam trawlers working gear on right</td>
</tr>
<tr>
<td>c.1900</td>
<td>Numbering of lifeboats with No.1 on right</td>
</tr>
<tr>
<td>c1863</td>
<td>Evidence that Master's cabin was on right</td>
</tr>
<tr>
<td>c1805</td>
<td>Lord Nelson's favourite seat was on right</td>
</tr>
<tr>
<td>c1794</td>
<td>Evidence that Master-at-Arms hammock was slung on right</td>
</tr>
<tr>
<td>c1705</td>
<td>Medial steering wheel</td>
</tr>
<tr>
<td>c1500</td>
<td>Medial whipstaff</td>
</tr>
<tr>
<td></td>
<td>Evidence of medial rudder with tiller to right of stern post</td>
</tr>
<tr>
<td></td>
<td>Development of medial rudder in occident</td>
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<tr>
<td></td>
<td>Symmetrical steering arrangement of 12th cent. vessels</td>
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<tr>
<td></td>
<td>Nordic long-oar steering sweep on right (starboard)</td>
</tr>
<tr>
<td></td>
<td>Roman Corbita with symmetrical steering arrangement</td>
</tr>
<tr>
<td>c500 BC</td>
<td>Craft with steering oar on right</td>
</tr>
<tr>
<td></td>
<td>Medial steering artifact 4000-2000 BC</td>
</tr>
<tr>
<td></td>
<td>Paddle evidence from c7000 BC</td>
</tr>
<tr>
<td></td>
<td>Evidence of first navigation</td>
</tr>
</tbody>
</table>
|           | Right-hand- referring man from 10 000 BC.
a. Of the four basic forms of transport studied - land, water, rail and air - water transport exhibited the greater effect of the influence of side-preference but not necessarily of human handed preference even though those two factors were most likely inter-related.

The evidence studied showed that with those craft where the propulsion and steering depended primarily on human power the influence of human laterality was more pronounced than in those craft which had mechanical propulsion. As an example, the single paddle canoe and Polynesian outrigger craft were usually operated with the paddle on the preferred-hand side so that right-hand-preference was traceable as an influence throughout the history of these types of craft.

b. In vessels with mechanical power and where the operator was constrained to one position, such as small motor-boats, there was evidence for a preference to sit on the right of the craft medial and, as noted in 3.1.1.a, recommendations for power boat design in the USA were based on a rule-of-the-road derived from 19th century practice and not because of hand-preference or mechanical design; so that the driver's position was on the right.

c. Side nomenclature for describing the left and right bilateral division of a hull-port and starboard- was unequivocably stated by all the authorities studied as having its origin with the preference for the steering artifact to be mounted on the right; as described in 3.1.

It was concluded that, on the basis of cause and effect, the general custom of fixing the steering artifact on the right side of a vessel, which was evident in all parts of the world and for which there were very few contrary examples, came from a cause of equal universality; namely human lateral preferences.

* see 3.1.3 g page 143
d. The nomenclature of social positional precedence was clearly based on human side preference but the nomenclature of a vessel's principal components relative to the fore and aft medial were not clearly referrable to human preferences. Station and compartment numbers tended to start with No. 1 forward and to the right-side with odd numbers for other stations on that side. Whistle signals—one blast to indicate a turn to the right and two blasts for left—along with even numbers for stations and compartments on the left of the medial, were consistent with the social precedence scale in which No. 1 person was to the right. However, it could not be concluded that there was anything more than a very tenuous relationship between nomenclature and human hand and side preference.

Among the social behavioural factors of the man at the control interface, the question of the influence of social precedence was answered positively by the layout of control position equipment in many modern ships. The distinction between the operator who manned the primary controls and the operator who was in command was reflected by placing the former on the control position medial and the latter to the right of the medial but able to move to the other side of the medial to improve the view of the external environment. The preference for the right of medial station was apparent in many reports studied particularly those dealing with modern ships' control positions. Right-side preference was also apparent at control stations at which the operator did not have direct visual perception of the external operating environment and in which modern instrumentation and controls were unconstrained by mechanical requirements to one particular side.
e. Rule-of-the-road. No conclusions were reached concerning the origin of the keep-right basic rule. One possible origin, as described supra, was on the preference for a ship's commander to control from the right-side of the medial. Whether this was the cause and the rule the effect or whether the rule was the cause and the right-side position the effect could not be decided from the available evidence. Only the convenience of the causal chain of facts concerning social precedence could be noted.

f. Working gear. It was concluded that the preference for working gear to be on the right side was an example of tradition related to the preference for the operator to be to the right of the medial if not constrained to the medial position.

g. Sheet anchor side. The differences noted in section 3.1.2 provided conflicting evidence for the origin of the sheet-anchor side and therefore, it could not be stated that human lateral preferences had any influence.

h. Environment. As a cause of side preference, the environment was discounted other than when considering the preference in British warships to carry the reserve (sheet) anchor on the right. Otherwise the evidence was against this.

j. Chance, human laterality or operating convenience.

The three principal origins considered for all types of vehicles were related to marine and riverine craft as follows:

Chance:

The rule-of-the-road in open waters and in rivers, as finally established by legislation in 1863, appeared to be primarily the result of chance rather than human laterality or operating convenience even though the former conveniently fitted a causal chain linking hand and side preference with the keep-right and give-way to the right rules. (see 3.1.10.e).
Human laterality:

The steering artifact on the right and thereafter ship's nomenclature bilaterally about the vessel's medial, was part of a chain of causes and effects which included the senior position to the right and the tendency to make the right side the working side and the left the docking side. (see 3.1.10.d).

Operating convenience:

No evidence was found that the design of vessels and their equipment in general required any significant bilateral rules or practices; only the stereotype right-hand screw which affected the way in which a ship manoeuvred, could be said to be an example of rules and practices based on operating convenience. The Venetian asymmetric hull gondola, 3.1.3.e, was the result of human laterality and not the cause; similarly with the twisted stern craft of China, 3.1.3.d, which might be the result of human laterality.

* as described in 3.1.3.g page 143
Appendix A.

Comments on summary of hand and side-preference factors in ships which was published in the *Mariner's Mirror*, February 1972, p.107.

Henderson, D.M. 1972:

"L.F.E. Coombs (The *Mariner's Mirror*, February 1972, p.107) seems to imply that the Royal Navy always 'drove' on the right. This is not correct. When on manoeuvres the ships kept to port, until well into the twentieth century: and kept to starboard and applied the Rule of the Road only when approaching merchant vessels. The only literary reference I can recall at present is from *A Sailor's Odyssey* by Admiral Cunningham. Being at present 'at sea' I cannot give the page number."

Hogben, P.B. (1972):

"Further to the letter from L.F.E. Coombs on right-side-dominance (M.M. vol.5 § p.106, may I offer a few more thoughts for his consideration.

On Thames sailing barges, where master and mate shared the after cabin, the master's berth was always to starboard and the mate's to port, the lettering 'Certified accommodation for the master' and 'Cert. accommodation for one seaman' being cut into the deck beams on the respective sides (sometimes with quaint mis-spelling). I believe also that on square-rigged vessels the master's quarters were normally to starboard and in fact I have found special mention of the Clipper "Wild Deer" of 1863 as being an exception to this rule - '... her Master's accommodation was to port, instead of as usual to starboard...' (Paddy Henderson by Dorothy Laird, p.54).

Of two master mariners to whom I have put the question, one said that he would consciously take the starboard side of the bridge in thick weather, and probably did so unconsciously at other times. (The second had a conscious preference only for the warmer side!) However, it is my impression that in sailing vessels the master normally took the weather side of the poop, irrespective of whether the vessel was on port or starboard tack, even though on port tack the weather side would not, one imagines, give the best view of another vessel having right of way on the starboard tack.

Mr. Coombs might also consider the numbering of ships' lifeboats, where I have noticed that No. 1 is the forward boat to starboard, and the numbering frequently continues with odd numbers to starboard and the succeeding even numbers to port.

Could there even be significance in the allocation of sound signals, where the simplest - one blast - indicates the starboard course?"

Chowdhary-Best, G. (1972):

"L.F.E. Coombs's letter on right-sided dominance is of great interest, but I wonder if he has considered the possibility of right-eye dominance, as opposed to right-handed dominance, accounting for some of the phenomena he outlines?"
Sir Stewart Duke-Elder, in his *System of Ophthalmology* (IV, 1968, p.687) stated that in over 90 per cent of individuals one eye, the master eye, tends to be used more frequently than the other. The preference is established early in life and is maintained. In adults the right eye is master in about 64 per cent of cases and the left eye in 34 per cent. Although it is commonly stated that right-eye dominance and right-handedness go together, but this is not necessarily so; indeed 33 per cent of right-handed people show left ocular dominance, and left-handed people are approximately equally divided between right and left dominance.

Recent work in psychology provides some evidence to show that objects presented to the right side of the visual field are recognized more easily than on the left, when viewed for brief periods. This may or may not be relevant to the rule which he cites of giving way to a ship on the starboard side. Certainly it might be argued that senior officers stood to the right both for this reason and because they could be marginally more easily seen by their men when giving orders."

Phipps Hornby, W.M. (1972):

"With reference to Mr. L.F.E. Coombs's letter published in *The Mariner's Mirror* for February 1972, concerning right-side dominance: may not that stem from the circumstance that most folk are naturally right-handed?

As regards marine practice: I suspect that the preference for the right-hand side can be traced back centuries before the Dutch wars. Thus, for example, in models in the Science Museum, London, of a ninth-century Viking ship and a thirteenth-century ship, both carry their steering oar over the starboard quarter. The choice of the starboard position would seem not to have been invariable, but to have predominated.

Presumably the person directing the course of the vessel would have taken up his position so as to be near the steersman; which normally would have taken him to the starboard side. So possibly, with the efflux of time, the starboard side may have become the accepted position of the man in command.

On the specific point of the positioning of sheet anchors: it is so long now since I had anything to do with anchors that memory falters. But I have a recollection of being told that the reason why, in British men-of-war, the sheet anchor was stowed on the starboard side had to do with weather conditions to be encountered in the Northern Hemisphere.

As against that I have had a look at photographs of ships reproduced in *Jane's Fighting Ships*, 1914 edition. From that it would seem that the Imperial Japanese Navy followed British practice (at that period only to be expected). On the other hand, ships of the Imperial German and United States Navies carried their sheet anchors on the port side. (In the case of the German ships, I have been able to check against photographs in my own album.)"
3.2.1 The influence of hand and side preference upon the design of road vehicle controls and rules of conduct

3.2.2 The influence of RHP on the rule-of-the-road

3.2.3 The 'whip' causal chain

3.2.4 The 'sword' causal chain

3.2.5 Papal decree and French legislation

3.2.6 The drive on the right custom

3.2.7 The European keep-right rule

3.2.8 The keep-left rule and the automobile

3.2.9 Rule-of-the-road North America

3.2.10 North American legislation

3.2.11 Interim summary of road factors.
Section 3.2

Road vehicles.

3.2.1.

The influence of hand and side preference upon the design of road vehicle controls and rules of conduct.

(Automobile control factors are dealt with in section 3.3)

Evidence for the evolution of control equipment in the form of bit, bridle and reins was not available in history from which a reasonable assumption could have been made about the period in time when man invented control equipment and acquired the skills which eventually became stereotyped throughout the world.

All that could be assumed was that the left hand eventually became the 'bridle' hand and the right hand was kept free for holding weapons or implements. No conclusive evidence had been found which suggested that any specific groups of horseman, at any time, did otherwise. Pictorial evidence of right-handed horse control was classified as 'bow anomaly' or mistaken observation on the part of an artist.

The left, 'bridle', hand in the man/horse control interface was significant to subsequent handedness practice because, with majority of skills requiring a high degree of co-ordination, the preferred hand was the expected hand. However, the bridle hand was not invariably the non-preferred hand because about 6% of a horse-riding population might have been left hand preferring. In general the customs, the arrangement of the harness, the procedures for mounting, leading and the nomenclature associated with horse riding were related to a RHP population.
3.2.2. The influence of RHP on the rule-of-the-road

Historians had postulated that the pre-Napoleonic rule-of-the-road, keeping to the left side of the track, had derived from the preference armed men might have had for keeping their sword arms towards each other when meeting on a pathway. No clear supporting evidence was found for that line of reasoning. However, the more likely origin was that which stemmed from convenience of operation; as described in 3.2.3 and 3.2.4.

3.2.3 The 'whip' causal chain

It was considered that when drivers of horse-drawn vehicles came to use long whips to control a team they would have kept the equipage to one side of the track medial in order to avoid getting the whip entangled with trees or shrubs at the side of the road. Because of RHP the tendency might have been to keep to the left. On meeting another vehicle the keep-left tendency might have reinforced a choice to move further over to the left to facilitate passing.*

In addition to the convenience of operation associated with the use of a whip there was the causal chain which started with the wearing of a sword on the left side of the body by the majority RHP population.

Part of the 'sword' chain might have been the influence it had on the rule-of-the-road which might have started with the sequence of events for mounting a horse.

* The war chariots of Asia Minor were an example of the positions of the driver and the fighting-man arranged so that the latter was to the right of the medial thereby allowing freedom of movement for his right arm.
3.2.4.
The 'sword' causal chain

RHP had dictated a fashion in the 16th century of wearing a sword at the left side. In turn that dictated the procedure which had to be used when mounting a horse.

Assuming that, with the growth of urban populations, horses were led by their grooms to the door of a house then the tendency would have been to position the horse with its left side to the door. From that it followed that a rider, once mounted and intending to move off in the direction in which the horse was facing on the left side of the road, might have tended to keep to that side.

Having considered a journey to the left what happened if the intending journey were to the right? It was possible that, after mounting, the action of pulling the horse's head to the right and turning it to face in the intended direction of travel the tendency would have been to have gained the far side of the road; that is the left side of the rider. Therefore, over hundreds of years a combination of RHP, habit and convenience of operation predicted a keep-left custom as the basis for the rule makers who followed.

3.2.5.
Papal decree and French legislation

Road transport historians and commentators on hand preference had suggested that a Papal decree in the Middle Ages, see Barsley' (1966) p.164, had reinforced the common practice of keeping to the left and that was reflected by French legislation which stood until overthrown by Robespierre at the end of the 18th century. Another theory advanced was that the traditional order of advance for an army in the field was left-flank first; derived possibly from the Papal decree or might have had much earlier origins as evidenced by some of the orders of battle from
earlier times; Ref. Fuller (1970),

3.2.6. The drive on the right custom

Causal train of factors which started with an RHP population controlling horses with the non-preferred hand (NHP) so as to keep the preferred hand (PH) for weapons and equipment, such as the whip, was a logical progression in the modern keep-left rule. However, the branching causal chain which resulted in the post-Napoleonic keep-right rule was not as clearly definable for its origin or why it was adopted eventually for a large part of the motoring world.

Conjecture about the keep-right rule might start with the extensive highway system of late 18th century France on which whip wielding coachmen were unconstrained by custom or rule to one particular side of the road. The first significant link in the chain might have been the increase in military traffic in France at that time so that meeting another vehicle coming the other way was no longer an occasional event outside the larger towns. In particular, the postillions of fast equipages, who rode the left-hand side horse of each pair, might have adopted the safer practice of passing man-to-man, so that the clearance between animals and hubcaps was kept at a safe distance. With opposing traffic not in sight it was likely that the tendency would have been to use the crown of the road; a practice perpetuated by motorists in remote areas in the next century.

3.2.7 The European keep-right rule

The history of the keep-right rule in Europe was examined for origin by testing the three possibilities put forward by researchers and historians. Discussions were held by Hickman Robertson (see Ref. in Intro) who examined the question of rules of the highway, to obtain opinion on the most likely areas of fruitful research. There appeared to be few records of legislation and no accessible legislation before about 1830 concerning
the rule-of-the road. Hickman Robertson had concluded that in France in the 18th century there was a number of 'town' rules, some 'left', some 'right'.

The three possible reasons which were proposed for examination were:

(a) Napoleon I's tactic of advancing the right-flank first;
(b) Robespierre's predilection for 'reversing' existing rules;
(c) Military traffic convenience of driving on the right.

(a) Barsley, ibid, p.164, suggested that the European keep-right rule originated with a decision of Napoleon I to gain a tactical advantage by advancing the right flank of his army first thereby surprising the enemy who, presumably, had expected the traditional left-flank first move. To facilitate such a manoeuvre, the troops were ordered to keep to the right of any track.

No written evidence was found which supported the foregoing argument even though it was logical in its reasoning.

(b) Robespierre's predilection for reversing existing legislation, which included rules of Papal origin, was another possible explanation but it was not supported by any evidence. Considered as a separate subject for research was a survey of French military and civil legislation for the years 1775 to 1815 with the object of tracing the origins of the European keep-right rule.

(c) It was only conjecture that the keep-right rule reflected the Napoleonic tactic of advancing the right-flank first or was derived from convenience of operation when horse-drawn vehicles passed at speed on the military highways. Some researchers had suggested a connection between the two possible causes but there appeared to be no connection between the two. It was easy to construct diagrams which purported to show the relationship between them but when the great difference in numbers of events between highway movements and military engagements was
taken into account it was concluded that the keep-right custom of the road would have been the greater influence and which might, on occasions, have dictated the tactical deployment of troops.

Therefore it was concluded that the keep-right rule was derived from operating convenience and was similar to that which had applied in North America on the waggon trails. However, without factual evidence that was only conjecture and furthermore there was no evidence that the North American custom, as described below, influenced the French.

3.2.8
The keep-left rule and the automobile

The influence of right-hand-preference (RHP) in the evolution of road transport was evidenced by the retention, in all parts of the world, of the left-hand as the control (bridle) hand and the right hand as the 'whip' or 'sword' hand. At the same time, the evidence of the left- or bridle-hand preference as the principal control in the man/animal interface conflicted with RHP factors in man/machine interfaces in which the preferred hand, the right, was used for the principal control function.

In the United Kingdom and in those parts of the world not subjected to Napoleonic military influences, the continuation of the drive on the left practice, with drivers of wide vehicles sitting on the right of the vehicle medial (VM), presented no particular problems when the automobile entered the traffic scene. With a driver's position similar in location to that of the coachman, the rules-of-the-road applied with equal effect to animal transport and the automobile. One of the few problems which had a handedness origin was that of the led horse; either led by a pedestrian or from another horse. The practise of leading an animal from its left, nearside, was often reversed in heavy traffic going in the same direction so that the horse being led was away from the traffic.

According to the Enc. Brit. 14th edition, Roads, that was the practice
3.2.9
Rule-of-the-Road North America

The North American rule-of-the-road appeared to have evolved for similar reasons to the European rule but in isolation.

The trail waggoners, as described by Hornung (1959) p.30 et seq and by Rae (1971) p.12 et seq, such as those who drove the Conestoga wagons at the end of the 18th century, might have been the originators of the practice of passing to the right when meeting another team. There was no point in cross-referencing to the British rules because of the isolation of the Eastern colonies and the few rules at that time in Britain; the majority of which were applicable only to specific locations.

It was assumed that the emerging United States had devised its own rules-of-the-road based upon convenience of operation of the waggon trails which had opened up the interior of Virginia and Pennsylvania. The Lancaster Valley Trail in Pennsylvania was a notable example of the trails and waggoners referred to by Rae, ibid. Rae made direct reference to the rule-of-the-road and its origin in North America. On pp.13,14: "The Conestoga is also credited with helping to establish the movement of traffic on the right as the rule-of-the-road in America; instead of the left as in Britain. The teamster was always on the left of the waggon, either astride the near wheelhorse (LH), or walking or riding on the 'lazyboard', an oak board that pulled out between the two left wheels, from which the driver could guide the horses and operate the brake. The waggon therefore had to be on the right of the road for the driver to have a clear view ahead, and the lighter vehicles found it easiest to use the well-marked and firmly packed ruts made in dirt roads by the big Conestogas".
Rae's reconstruction appeared to be reasonable evidence for the origin of the rule and was one of only a few references available to the research.

Although the Conestoga waggoner's 'lazyboard' provided clear evidence of a control position to one side of a vehicle medial, influenced by long-established, European originating, 'nearside' and 'offside' definitions, it was nevertheless opposite to the coachman's customary position. Therefore that particular evidence provided an example of a mixed arrangement similar to that which was to be found at a later period when the automobile appeared. That was that the driver's position was not necessarily on the side of the vehicle closest to the middle of the track. The Conestoga waggoner walked or rode on the track medial side, whereas the North American coachman usually sat on the side of the vehicle away from the track medial; as illustrated by Fig. 3.2.a and 3.2.b.
Evolution of Rule-of-Road -- Pre-Napoleonic Fig. 3.2a.

Sword causal chain

RHP majority horseman sword-wearing horseman mounting left-side of animal leading draught animals

OFFSIDE NEAR SIDE

Postillion riding left mount of a pair Driver keeping equipage to left of track medial to give room for whip.

mounting horse which has been positioned with its nearside to the door or gate of a house

Turning horse to face other way. One possible origin of keep-left rule.

Coachman with passenger. Coachman sits to right so as to have whip-hand free.
NORTH AMERICA
Lancaster Trail, Pa, c 1775

French Military KEEP-RIGHT
c 1800

Subsequent city and national rules for 'Napoleonic Europe

DRIVE ON RIGHT RULE

DRIVE ON LEFT rule retained in United Kingdom and other countries not subjected to French domination.
3.2.10
North American legislation

From the practice of the waggoners came the gradual spread of road transport traffic and the custom of driving on the right which was reinforced by legislation, in the state of New Jersey, in 1813; ref. Rae, ibid, p.14.

A particular study of illustrations of road and trail traffic in America extending from about 1775 to the time of the automobile, showed clearly the European derived custom of leading a draught animal at its left side and the control of teams hauling a coach from the right-hand seat. Hornung, ibid, referred on page 35 to: "Driving down Broadway (New York) and keeping near the west side" i.e. the right-hand side. That referred to the traffic situation in a typical American city in 1835.
Interim summary of road factors

To summarise the sub-section dealing with road vehicle factors:

a. In the United Kingdom certain towns passed local rules about keep-left and in 1847 the Town Police Clauses Act clarified the legal position so that the practices which had derived from the 'sword and whip' causal chain remained unchanged in Britain. In other words, both government and local authorities were content to keep the 'natural' rule of keep-left.

b. In France there were local rules in the larger towns at the end of the 18th and the beginning of the 19th centuries. During the military and political domination of Europe by France the drive-on-the-right custom was established and then reinforced and clarified legally by legislation on at least two occasions; 1830 and 1860. The origin of the French drive-on-right custom was possibly with one or a combination of three causes:

   (1) A Papal 'keep-left' ordinance reversed by Robespierre
   (2) Napoleon's 'right-flank' attack
   (3) Military convenience

Of the foregoing (2) was considered the least likely.

c. Evidence for the 'French' rule was the unchanged Papal and British keep-left rule in those parts of Europe which had not been subjected to French administration, i.e. parts of Austria, Hungary, Slovakia, Sweden and Portugal.

d. In North America a keep-right custom may have evolved in isolation of European practices. The origin of the rule-of-the-road appeared most likely to have been with waggoners of the commerce trails of Pennsylvania and Virginia in the 18th century. Once one state had passed legislation (New Jersey in 1813) the others would have followed with the same rule.
The growth of urban road traffic at the end of the 18th century encouraged the introduction of rules in order to prevent chaos in conflicting situations. Traffic conflicts were often sorted out by the co-operative actions of drivers who applied common sense and took correcting actions. Only at specific awkward locations, such as London Bridge, was it necessary for local authority to intervene with a rule.
Section 3.3

Road vehicles - automobiles

3.3.1 The evolution of controls and rules of conduct
3.3.2 The rule-of-the-road
3.3.3 Seating position
3.3.4 Preferred hand and the primary control
3.3.5 Preferred feet
3.3.6 Social factors
3.3.7 Operator's environment
3.3.8 Special vehicles
3.3.9 Physiological and psychological factors
3.3.10 Social environmental factors
3.3.11 Scanning patterns
3.3.12 Analysis of automobile factors and conclusions
Section 3.3
Road vehicles—automobiles

3.3.1. The evolution of controls and rules of conduct

The influence of horse and animal transport practices

The steam road vehicles, which were experimented with from about 1800 onwards and which reached their peak of popularity in 1840, were alternatives to the horse-drawn coaches and therefore they used the same track and were in the same operating environment. They did not introduce any control position practices significantly different from those of horse-drawn vehicles. The rules-of-the-road, at that time primarily ones of convenience rather than legislative, applied equally to both forms of road transport. However, at the peak of interest in the steam coach the keep-left rule was increasingly being applied and in 1847 the Town Police Clauses Act (10 and 11. Vict. c89) settled any disputes or misunderstandings by requiring all vehicles in the towns to keep to the left when meeting another vehicle.

Following the rapid improvements in railway technology and the extension of routes to form what was to become for the next 100 years Britain's basic passenger and freight transport system, the use of the steam carriage declined rapidly. Between about 1840 and 1880 experimenters continued with the development of steam power and traction for farm machinery, road haulage and for private vehicles but the overall road traffic scene in all parts of the world remained the domain of the horse-drawn vehicle. Not until after 1880, when the internal-combustion engine became a practicable means of power, did a change take place. However, the automobile was only slowly developed so that its use on the roads was for many years infrequent. It did not, like the aeroplane,
grow in capability and numbers in just ten years. The internal-combustion engined car merged into the traffic scene and the driving rules and customs were dominated by the established practices of animal transport.

The side of the road on which to drive was either established by custom or legislation. The seating position and the use of specific hands for specific control actions were influenced by horse transport.

3.3.2
The rule-of-the-road

No exclusive national rules-of-the-road for the operation of automobiles were made in the first three decades of the 20th century. The car driver had to conform to the established customs and rules. However, the higher speed of cars in general had to be matched by a number of road regulations framed to reduce collisions in conflicting situations.

3.3.3
Seating position

The driver in the early days of cars sat on or towards the right side of the vehicle thereby reflecting the influence of the coachman's position; as described in Section 3.2.

The majority of the specific types studied, particularly as exhibited in museums, at enthusiast's trials and in Scott-Moncrieff (1963), not only provided clear evidence of the retention of the coachman's position to the right for the first three decades of motoring, but more importantly the use of the left-hand for steering control and the right-hand for secondary control.

3.3.4
Preferred hand and the primary controls

The preferred hand for primary control when using reins, the left hand, was, in general, a stereotype for the primary steering control
practice for cars. The controls for the first three decades of the automobile were usually arranged so that the expected preferred hand, the right, operated the brake and gear levers. In different times and in different parts of the world the relationships between rule of the road, seating position and the allocation of hands and feet to specific control functions underwent changes. Fig. 3.3.a was constructed to illustrate those relationships.

It was recognised that to describe the use of the hands for specific control functions was a generalisation because coachmen would use both hands on the reins just as did the car driver on the wheel.

3.3.5
Preferred feet

The automobile was the first extensively used vehicle type in which the operator's feet became part of the mechanical control interface. Apart from footedness, which was not usually as clearly discernable as handedness and one exception the brake control, there were no established control practices from animal transport which designers could use as a guide when arranging the pedals. The one exception was the brake lever or pedal, which on the majority of horse-drawn vehicles was set to the right side of the driver's position. Therefore, the choice of the right pedal of two pedals or more might have been influenced by the earlier forms of transport. (It was noted in sub-section 3.2 that the Conestoga waggons in America had the brake control lever on the left side.)

3.3.6
Social factors

The automobile introduced, eventually, its own set of social factors many of which remained unresolved over 70 years later. This study of laterality was concerned only with the question of social precedence and the relationship between master and servant.
Driver to right of medial

British driver on right of vehicle medial and close to road centre.

European driver on right of vehicle and close to side of road.

Early automobile

Early automobile

Right-hand drive

Left-hand drive

About 1930 in Europe

Sweden before 1968

Racing cars. Right-hand drive

Present day British

Europe present day

Rules-of-Road — Automobiles Fig 3.3a
The coachman, sitting usually to the right side of the coach, was the servant; in practice if not by definition. The master sat to the left, if sharing the driving position, and in doing so provided an example of a practice contrary to the right-side precedence influence which was considered in section 3.1.

When the world's automobile population became fragmented into different driving positions and rules of the road, each area introduced its own set of lateral factors to which the majority of the social factors were subordinated.

3.3.7
Operator's environment

By about 1930 there were the following operator environments:

(a) left-hand rule of road with driver to right of vehicle medial;
(b) left-hand rule of road with driver to left of vehicle medial;
(c) right-hand rule of road with driver to right of vehicle medial;
(d) right-hand rule of road with driver to left of vehicle medial;

Of the foregoing (a) and (d) became standards so that drivers became accustomed to sitting on the side of the car which was closest to the centre line of the road.

Fig. 3.3.b summarises the different driving positions and rules of the road:

- Britain 1970
- Sweden before 1968
- N. America and Europe before c 1925
- N. America and Europe c 1970
3.3.8 Special vehicles

The many exceptions in different countries were noted. For example, some service vehicles such as postal vans and road sweepers had the driver's position on the side closest to the edge of the road. In Switzerland, postal-motor coaches were right-hand drive and thereby perpetuated the 'coachman' practice. Furthermore, irrespective of the keep-left rule a Swiss postal-coach driver could insist on taking the side of the road furthest from a precipice when meeting another vehicle coming the other way.

3.3.9 Physiological and psychological factors in road vehicle control

Physiologically the automobile driver was in a 'skewed' man/machine interface because of the established tradition of placing the driver's position to one side of the vehicle medial.

Psychologically the automobile driver was in a control skill situation in which the dynamics of the vehicle and the instrumental interface were subordinated to the extravehicular factors. The presence of hazards and their detection and avoidance dominated the control actions of the driver. Scanning of instruments and controls was not an important item in the scenario of control events.

Evidence from drivers who regularly experienced driving on the other side of the road or driving from the other side of the car, after crossing frontiers, did not indicate that there was a difficult task of adaptation to a new set of control actions and perceptual inputs. If there had been considerable evidence of drivers finding great difficulty in changing over to a different driving position or driving on the other side of the road then that might have supported evidence which showed that there was a special set of physiological and psychological factors related to hand and
side preferences. No such evidence was found other than references by human factors researchers to the risk of reversion to a set of reactions, in an emergency situation, which were inappropriate to the rule-of-the-road.

Therefore, it was concluded that the automobile driving position was not one which provided evidence of strong hand and side preference influences other than those which had been derived from the coachman.

Apart from the side of the road rule, a driver was usually in a symmetrical perceptual environment. Events which cued actions occurred both spatially and temporally in the periphery of the car's envelope to a pattern which generally resulted in as many occurring to the left as to the right. The train of events, represented by road-side furniture, including parked vehicles, was matched by fewer, but more hazardous, events in sequence on the driver's side of the car.
3.3.10
Social environmental factors - road vehicle operation.

Lateral factors, represented by the use of the right hand for holding the whip when driving a coach, dominated the social precedence spatial order. The coachman preferred to sit on the right-hand side irrespective of his social position relative to the other occupants of the vehicle.

The coachman's behaviour, reflected in the lateral control of the vehicle in the operating environment, depended on a number of factors among which were the following:

a. The existence or absence of rules-of-the-road; enforced by custom or by legislation.

b. The nature of the road and verge surfaces and topography which might make a passage to one particular side less hazardous.

c. The type and speed of opposing vehicles.

d. The relative social precedence of the owners and drivers of opposing vehicles.

e. The importance of guarding against an attack from an opposing vehicle.

The foregoing factors, plus others, related to the control of a vehicle and to the characteristics of a vehicle as modified by the influence of an operator's laterality. In general it was found impracticable to consider simplified models of the operator/vehicle/environment because of the large number of variables: some variables reinforced the effect of an operator's laterality, others modified those effects.
3.3.11
Scanning patterns

Scanning patterns of the drivers of road vehicles based on the theory of attention to the left or right-field, as considered in section 1, were not of significance either for horse-drawn vehicles or for automobiles. It was assumed that instantaneous attention to the right-field by a horseman, for example, was of small consequence because there were many other actions requiring attention to both fields of visual perception, that it was only an academic exercise and outside the limitations of this thesis to consider them in depth. However, scanning of far distant features of the road and the scenery might be found to be primarily dextrad until a specific 'goal' feature was located.

Recourse was made to the British Road Research Laboratory's (RRL) experiments with eye-marking equipment, which showed the attention point of a driver's eyes, to see if there was any lateral asymmetry in the scanning patterns: also to Forbes' (1972) references to Learning, Search and Scan Patterns.

The RRL had conducted a number of experiments but none of the results was repeatable or significant enough to warrant publication because, in general, the visual perceptual behaviour of drivers was random within the forward arcs of attention. As an example, in one series of tests it was apparent that the driver's attention was directed for the greater part of the time at a roadside advertisement, despite the hazardous nature of the traffic situation. The RRL was not able, within the limitations of the research, to analyse the complex attention scenarios which were recorded.

The RRL confirmed the generalisation made in this thesis that car drivers were concerned primarily with external visual cues and that instrumental scanning was of secondary importance and was not comparable with that found with other man/machine interfaces. Therefore, without a definite pattern of scanning of instruments and with few instrument
layout stereotypes among the many different types of automobile it was not possible to correlate any external scanning behaviour with that of instrument scanning patterns.

Overall the automobile interface did not lend itself to detail analysis because of the variety of control and instrument arrangements and the great variations in the skills and attitudes of the operators.

3.3.12
Analysis of automobile factors.

a) The automobile exhibited symmetry in plan about the usual axis of motion so that the principal parts were disposed bilaterally, symmetrically about the vehicle medial.

b) The driver's position was not generally on the vehicle medial but to one side; that depended initially on the 'coachman' tradition of sitting to the right but once large-scale car production proliferated the automobile and started the 'car-age', the driver's position became standardised on the side closest to the track medial. However, no evidence was found of legislation which prescribed the 'driving side' or of facts contrary to those which had indicated that the driver-on-the-right position of the early cars was derived from the coachman practice.

c) The operating environment imposed restrictions on the majority of cars by the legal requirements that operators had to keep their vehicles to one side of the highway when meeting another vehicle and, overall, were required to restrict the use of their car to the public highway; there was no freedom of manoeuvre comparable to that of the ship and the aircraft. Essentially, the private automobile and public service vehicles were semi-track guided systems. Huddy (1922).

d) The driver's hand and side preferences were considered in relation to the skill requirements in order to determine their significance to the research:
When the car first appeared as a practicable alternative to animal transport the traditions of the coachman and the horseman were adopted for the new form of transport and, as noted supra, the preferred hand of the majority, the right, was not used for the primary control of steering. The 'reins-hand', the left, was retained for steering and for at least three decades the controls were usually arranged with the handbrake and gear levers to the driver's right hand. When necessary, both hands would be used on the steering wheel and eventually the primary controls of foot operated throttle pedal and brake pedal introduced a new set of driver-skills in which handedness was of no direct consequence.

e) The modern automobile exhibited two distinct examples of evolutionary paths which were opposite in effect. The world's cars in the 1920s were roughly divided between those with left-hand drive and those with right-hand drive. With the exception of Sweden until 1968, the driving position for all but a few specialist-function vehicles was to one side of the vehicle away from the side of the road so that drivers passed cars coming in the opposite direction 'man-to-man'.

f) The automobile was found, after consideration of all the available facts, to be an example of traditional control position practice, 'coachman', which was abandoned in many countries in favour of a position, relative to the vehicle's medial, related to convenience of operation. That meant that in those parts of the world in which the driver sat on the left the left-hand was on the primary steering control. In those countries in which the driver sat on the right the right-hand was used on the primary control.

The foregoing analysis described the different practices in the light of the driver's handedness rather than on the basis of the acquisition of the special skill of driving. Once again it was found that human adaptability to circumstances and in particular to the acquisition of a new
skill, tended to override any problems which might have arisen from the incompatibility of the operator's handedness with the machine interface.

g) The social environmental factors were not found to be of significance in the operation of the modern automobile.

h) Scanning patterns by drivers obtained from research using eye-marking techniques did not provide significant evidence of the influence of the dextrad writing form or of differences in attention between the left and right visual fields. However, this was considered to be an area of research which had not been fully explored and therefore no positive conclusions could be reached. Recommended for future research is the relationship between laterality and driver behaviour using the factors which were summarised by Kimura (1973) particularly the differences between perception of stimuli from the left and right-fields of vision.
Section 3.4

The Steam Locomotive

3.4.1 Introduction

3.4.2 Evolution of the Control position

3.4.3 Control ergonomics

3.4.4 The working area

3.4.5 Driver's position and the rule-of-the-road

3.4.6 Perceptual factors

3.4.7 Social factors

3.4.8 Summary of steam locomotive control interface laterality factors

Illustrations to section 3.4

Fig. 3.4.4 Typical 19th century steam locomotive control position - Britain and France

Fig. 3.4.5 Handedness and controls of the steam locomotive
The Victorian steam locomotive and the ergonomics of its control position were related to the stationary engine. There was no Georgian steam railway and only a few experimental locomotives in the reign of William IV, to which the designers of the first production steam locomotives could turn for guidance when arranging the controls. The steam railway engineers of the 1840s and 1850s, the period of rapid growth in locomotive power and use, were in a similar situation to that of the early steam-ship constructors: there were few precedents and no ergonomic standards, other than right-hand-preference. Overall, the demands of making the machinery work dominated any consideration of human factors.

Evolution of the control position

In 1804 when Trevithick built his Tram engine, as a steam powered alternative to horses, he arranged the controls in such a way that the driver could walk alongside the front of the engine as if he were leading a team of horses. It was inferred from illustrations that the driver walked to the left of the locomotive; that is, on the equestrian 'nearsid'.

It was not until it was found that a steam locomotive could be made to go faster than a man's walking pace that provision was made for the driver to ride. On Stephenson's early locomotives a platform was fixed to the side of the boiler on which the driver could crouch among the mechanism with his hands at the controls. Later, Stephenson, with the Rocket, fixed what eventually became the stereotype control position. This was at the firebox-end so that the crew of two could work together. The fireman had
to be close to the fire-door and the fuel bunker and, therefore, the
driver, who could have been in another position, was provided with
controls mounted on the back of the firebox. A platform was provided
for the two men between the engine and its tender. Although the view
ahead might have been improved had the driver been at the front-end he
not only would have been out of contact with the fireman but he would not
have been able to keep watch on the machinery of the locomotive. Had
the stereotype control position been established at the front of locomo­tives the driver's visual perceptual task would have been simplified
and the lateral arrangement of equipment and trackside furniture, such
as signals, made less complex.

3.4.3
Control ergonomics.

Much of the evidence of steam locomotive ergonomics is retrospective
because in the 19th century and for many years after there were few studies
made of the working conditions of locomotive crews. ref. Reynolds 1884.
There are no records comparable with those of aviation, for example, which
comment on the operation and arrangement of a vehicle's controls and the
associated human factors. Mechanical requirements, in general, dominated
design decisions so that human laterality, as a specific area of research,
was not studied.

The controls were extended and mounted close to the footplate, as
noted supra, but they were not necessarily designed and positioned either
for ease of operation or in relation to the design of the control position
as a whole. Levers and wheels designed with little consideration of their
user's hand preference continued as one of the ergonomic features of the
steam locomotive well into the 20th century; particularly in Britain.
ref. Tuplin (1963 and 1969 in particular). However, that recurrent theme
of retrospective ergonomics, adaptability of the human operator to adverse
circumstances, was an important aspect of locomotive operation. A factor which in association with the fact that few controls were of a type which required sensitivity of touch and hand and eye coordination made considerations of lateral preference less significant than in other forms of transport.

The influence of human laterality, however small, depended on the side to which the driver was positioned. If on the left of the medial his right arm and hand, which in the majority of drivers would be the preferred, was used for most of the control tasks requiring effort. If to the right, then the left arm and hand was used more than the right. Again human adaptability to a control arrangement, not matched to hand-preference, as noted in section 1, negated research and therefore records on which to reach any positive conclusions.

Apart from the possible influence of the coachman's right-side position on the design of early locomotive control positions, no evidence was found that the steam locomotive had been influenced by the design of the control positions of other forms of transport.

3.4.4.

The working area

The working area of locomotive control positions in 19th century Britain, as shown in Fig. 3.4.4, was smaller in plan than might be assumed from an external view of the cab. Fig 3.4.4 shows how the plan area of the footplate was encroached upon by the boiler, wheel arches, controls and equipment. The driver and fireman had to share a floor space which, in some types of locomotive, was only about 1.5m². The applicability of the space available to human laterality factors in locomotive operation is with the stance adopted by right-hand-preferring firemen who, as depicted in Fig 3.4.4, fired with the left foot forward and with the right hand on the handle of the shovel so that his ergosphere was offset to the left of the footplate medial. In a right-hand drive locomotive the driver was not
Typical 19th century steam locomotive control position—Britain and France.

Depicted is a right-hand drive engine with a right-hand-preferring fireman whose ergosphere is to the left of the vehicle medial VM.
so much in the way of the fireman as he was when standing on the left of the footplate. Ref. Tuplin (1963) p.155. Therefore, in some ways a right-hand drive locomotive represented a better arrangement of the controls in which the ergospheres of the two men were less likely to conflict; particularly when the footplate was narrow. However, that all this was the result of deliberate design decisions was not evident from the literature and records available for the research.

3.4.5
Driver's position and the 'rule-of-the-road'.

The steam locomotives used on the early railways in Britain were right-hand drive, despite the establishment of a 'keep-left' rule for parallel tracks. The former might have been derived from the 'coachman's' position, as noted supra, or from right hand and side-preferences. The keep-left running might have derived from the rule of the highway or equally from chance. There was no positive evidence available from which to determine these origins.

With signals, platforms and other trackside furniture, in general, to the left of the track in the direction of running, the steam railway in Britain and France and those countries influenced by them, exhibited a side demarcation analogous to the 'docking' and 'working' sides of ships.

It was not until the 20th century that the railways of Britain adopted, as a standard, a driving position to the left of the medial. Up to that time although the keep-left rule was standard many railways retained the 'Stephenson' right-hand drive. At the end of the 19th century the best location of signals relative to the track to which they referred was found to be on the left. At the same time, as boilers became larger in diameter and obstructed the driver's forward view, it was found preferable to place the driver on the same side as the signals. It was noted that
there remained many exceptions to this practice. Despite at least one accident caused by a driver becoming spatially confused over signals, because the expected relationships did not match the real arrangement of signals relative to the tracks, locomotives continued to be built with right-hand drive for operation on 'keep-left' railways. Ref. Accident Norton Fitzwarren 1940.

Fig. 3.4.5 summarises the different lateral arrangements of equipment on steam railways.

3.4.6
Lateral perceptual factors

In the other forms of vehicles studied the operator was usually presented with similar azimuthal arcs of view to both sides of the vehicle. In the steam locomotive the driver's forward azimuthal vision was occluded by the bulk of the machine so that he had two different sets of visual perceptual data; one to his left and one to his right.

Consideration was given to the 'favoured' fields-of-view theories, as noted in section 1, to see if there were any factors relevant to the perceptual behaviour of steam locomotive drivers. It was concluded that there were few if any relevant factors because the driver's critical attention point was usually well ahead and therefore within a narrow angle of vision. Only the outline of the locomotive's bulk in front of the cab and to one side affected a driver's ability to get visual perceptual data from one sector as easily as that from the other sector. The random appearance spatially in the driver's forward view of signals and other track-side features in the majority of railway situations prevented any detailed analysis based on visual scenario constructs similar to those which have been used for other forms of transport.

3.4.7
Social factors

Side precedence, which was a discernable influence on the design of
control positions and on the operation of ships and aircraft and to some extent automobiles, appeared to have no relevance to the steam locomotive and other forms of railway vehicle.

3.4.8
Summary of steam locomotive control interface laterality factors

(a) The influence on the design and operation of steam locomotives from other types of transport was found to be insignificant.

(b) The controls were not generally of a type which required coordination of touch, strength and eye and, therefore, were not significantly dependent on hand and side preferences.

(c) Overall the railways of the world eventually exhibited an approximately balanced bilateral arrangement of train and track-side equipment so that there were no stereotype side factors applicable world-wide and which were comparable to those aspects of equipment and operation of ships and aircraft which had been influenced by human laterality. For example, there was no internationally understood 'nearsid' and 'offside', no 'port' and 'starboard'.

(d) Section 3.4 in draft was shown to Dr. W.A. Tuplin of Sheffield University because his comments on the practical operation and on the design of locomotive positions had formed the basis of much of the research. He made the point, relevant to the preferred operating side of the control position, that: "An engine driver should not be close to vehicles running in the opposite direction to his own as he may be hurt by things projecting from them, and he should preferably be on the 'nearsid' where the station platforms usually are and where anyone giving an emergency warning is likely to be."
Dr. Tuplin's reference to 'nearside' is a good example of nomenclature from one form of transport eventually becoming inappropriate when the 'rule-of-the-road' changes for other reasons. The 'nearside' on Britain's keep-left tracks is opposite to that of keep-right railways such as those of German and North American origin.

<table>
<thead>
<tr>
<th>1830-1850</th>
<th>Britain and France</th>
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<tr>
<td>1850 - c.1920</td>
<td>No standard position in Britain and France and associated countries.</td>
</tr>
<tr>
<td>1840-1972</td>
<td>Germany and North America and associated countries.</td>
</tr>
<tr>
<td>1920-1972</td>
<td>Britain</td>
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Fig 3.4.5

Handedness of control positions—steam locomotives.
Section 3.5

Aviation

3.5.1 Introduction and limitations of research and explanation of the terminology used

3.5.2 The influence of human laterality in general

3.5.3 Summary of handedness, side preferences, traditions and aerodynamical and mechanical influences used as the basis of the research

3.5.4 Hand and side-preference influences. 1903-1914

3.5.5 Hand and side-preference influences. 1914-1972

3.5.6 Research into human laterality and its effects in aviation
   a) Human laterality
   b) Laterality and accidents
   c) Lateral nomenclature in aviation

3.5.7 Summary and conclusions for section 3.5

Illustrations to section 3.5

Fig 3.5 Illustration of terminology

3.5.3a Left-hand circuits
3.5.3b Right-hand drive automobile
3.5.3c 'Wright' method of control
3.5.3d Ambidexterous and handed joysticks
3.5.3e Keep-right rule
3.5.3f Torque reaction
3.5.3g Aircraft carrier
3.5.6 Pilot's visual frames
3.5.7 Principal lateral arrangements of controls and instruments on an aircraft flight-deck
Section 3.5
Aviation

Section 3.5.1
Introduction and limitations of research

Basic factors examined:
(a) The lateral characteristics of pilots.
(b) The influence of rules and practices from other forms of transport.
(c) The constraints from mechanical and aerodynamical factors.

Out of the great body of aviation history only the man-carrying, powered, controllable flying machines were given a detail study of the influence of human laterality on their design and operation. Of the lighter-than-air craft, balloons were not studied because they were uncontrollable craft and there was, therefore, no definable man/machine interface within the overall definition of this thesis. Airships were referred to in the research but with few extant types there was little opportunity to study their man/machine interfaces and the associated human factors. Only in North America, with the US Navy and Coast Guard, were large numbers built but all were to a basic design so that there were few variations which would provide evidence of human laterality factors.

The aircraft had an important place in the thesis because for many years it represented the most advanced and complex form of transport. Not until the advent of space exploration in the 1960s was it necessary to equip vehicles with similar comprehensive one-man/machine interfaces in which the operator had to exercise both short and long time prediction skills.

The aircraft control position remained comparatively simple for the first ten years of powered flight; thereafter, as each new performance frontier was crossed, more instruments and controls had to be added to
enable the human pilot to remain in the control loop.

The fundamental lateral factors were established early on in the history of aviation and, with the exception of the position of the principal pilot relative to another, no departures were made to the left-side and left-turn preference until the helicopter entered the transport scene in numbers sufficient to warrant attention to the adoption of a new control position stereotype.

Explanation of terminology used in this section.

Control of a fixed wing heavier-than-air flying machine, both powered and unpowered, is about the three axis of Roll, Pitch and Yaw. These are related as shown in Fig. 3.5.

During the first ten years of powered flight there was no standard terminology for the control surfaces and equipment and this sometimes caused misinterpretation. By the end of the period the three axis of control were effected through the following surfaces:

Roll by means of ailerons on the outer sections of the wings.
Pitch by means of an elevator on the forward or aft stabilizing horizontal surface.
Yaw by means of a rudder set vertically on the vertical stabilizing surface.

Fig. 3.5 Explanation of Terminology for Section 3.5
3.5.2
The influence of human laterality.

The influence of human laterality on the design of aircraft controls and on their location, on the position of the pilot relative to the medial and on the rules of conduct of aircraft relative to an airfield and other aircraft was clearly discernable in both early and later aviation development.

The control of an aircraft was considered in relation to the hand and side preference factors and control skills of other man/vehicle systems.

The horseman, for example, was both the person-in-command and the operator of the 'controls'. A similar man/vehicle interface was apparent with the following: cyclist, small boat operator, skier, the motorist and the drivers of all uncomplicated vehicles and craft in which the operator became in effect an extension of the vehicle and vice-versa.

In the same way the pilot of an aircraft was both the primary decision maker and the operator of the controls. This was a man/machine control loop requiring considerable skills of coordination and fast reaction and response to events.

Unlike the ship and the larger types of airship, from which aviation adopted terminology and some rules of operation, see sub-section 3.5.6.c, the person-in-command and at the controls did not move about the control position. That meant that human laterality factors had a significant influence on the design and on the disposition of the controls (as with other vehicles in which the operator kept to one seated position).

When the operator of a vehicle remained in one position, usually seated, the controls had to be arranged to suit his limbs for hand and foot operation. In other words, the ergosphere was limited.

The few examples of social precedence influencing the positioning of controls were not perpetuated and the modern stereotype of two side-
by-side seats, with the principal pilot operating the left-hand set of controls, was used in all parts of the world for all types of large aircraft; as discussed supra, the helicopter was an exception to the apparent rule because the principal pilot's position was to the right of the medial.

No evidence, other than the principal pilot on the left stereotype, was found of aircraft control station positioning which had been influenced by social precedence other than the early British practice for large aircraft of, apparently, adhering to the naval tradition that the principal position was to the right.

The only social behavioural factors apparent as an origin were the customs and rules from which evolved the left-hand circuit.

3.5.3
Summary of handedness, side-preference, traditions and aerodynamical and mechanical influence.

(a) Human lateral factors:
right hand preferring majority and dominance of right-hand position.

(b) Traditional factors:
left hand/anti-clockwise circuits used from ancient times by athletes, circus performers and for many motor-racing circuits.

Fig. 3.5.3.a
(c) The generally accepted practice of the driver of pre-1920* automobiles sitting to the right of the medial.

* pre 1935 quality European cars
pre 1930 " American cars

(d) The right-side preference at sea for command positions.

(e) The marine rule of the road.

(f) The decisions taken by the Wright brothers:
   (i) engine to the right, pilot to the left of medial;
   (ii) left-hand on control for pitch, right-hand on combined yaw and warp (bank) control.

(g) The possible preference by the Wrights to turn to the left because that was the side on which they lay or sat. The aviation historian Gibbs Smith in his research concluded that the left-turn and the anticlockwise circuit dominated the manoeuvring of aircraft during the first decade of powered aircraft.

The foregoing factors (a) to (g) were examined as a detailed study of hand and side-preference influences 1903-1914 in sub-section 3.5.4
(h) The influence on handling characteristics of the torque and gyroscopic effects of the clockwise (looking forward) rotating propellers and rotary engines used in Europe for the majority of single-seat aircraft in the formative years of 1914-1918. These effects are examined in detail in sub-section 3.5.5.

(j) The British 'ambidextrous' joystick.

The German handed (RH) joystick.

Fig. 3.5.3.d.

(k) The Paris Convention 1919 on aerial navigation; in particular the keep-to-the-right rule of an airway. One aircraft type, the Fokker FIII c.1920, had the pilot's position to the right of the engine but in a subsequent version the position was moved to the left of the engine to enable the pilot to observe landmarks on his left.

Fig. 3.5.3.e.
(1) The influence of high powered, racing sea plane development during the 1920s in which torque reaction had to be countered. (Ref. Baker, 1971).

![Diagram of a typical Schnieder Trophy racing seaplane with large propeller torque counterbalanced by asymmetric wing areas and/or asymmetric fuel tank arrangements.](image)

Typical Schnieder Trophy racing seaplane with large propeller torque counterbalanced by asymmetric wing areas and/or asymmetric fuel tank arrangements. (The 15 trophy races were run anti-clockwise)

Fig. 3.5.3.f.

(m) The aircraft carrier with 'island' to starboard.

![Diagram of an aircraft carrier with 'island' to starboard.](image)

Fig. 3.5.3.g.
3.5.4 Hand- and side-preference influences 1903-1914

This sub-section deals in greater detail with the factors listed in 3.5.3. The subscript numbers refer to the reference to Bibliography appended to this section.

A detailed study was made of the papers of Orville and Wilbur Wright and of the writings of others to determine the extent to which human laterality factors influenced the design decisions and flying habits of the early aviators.

Recorded comment on the influence of hand preference on the design of the controls of early aircraft and the piloting of aircraft in the period 1903-1914 were few. However there was one very important record which related to handedness and side preference. This was the training of a Walter Brookins to become a 'left-hand' pilot. He was trained to fly the Wright biplane from the right-hand seat of the two and the comments in the Wright Papers, McFarland (1953) and Harris (1970) provide one of the earliest records of handedness and its effects in aviation.

Training Brookins as a 'left-hand' pilot meant that the important wing-warping lever (roll-control) was operated by his left hand and not by the right hand as had become customary. In the Wright biplanes of those early years of powered flight there were two side-by-side seats, placed to the left of the engine as shown in Fig. 3.5.4.
Between the two seats was the principal control lever. At the 'outboard' knee of each pilot was a lever which controlled elevator (pitch control). See fig. 3.5.4. This was, possibly, an example of right-side preference dictating the arrangement of the controls. The Wrights appeared to have accepted without question that the majority of their pilots and pupil pilots would be RHP and therefore arranged the principal control lever at the right hand of the principal pilot's position. Brookins was deliberately trained as a 'left-hand' pilot so that he could control from the right-hand seat and train pupils who sat in the left-hand seat.

Many years later Orville Wright wrote a letter about the training of 'left-hand' pilots, apparently they were never able to fly using the 'right-hand' controls. A significant statement in the letter is Orville Wright's recollection of the time he, as a 'right-hand' pilot, sat in the right-hand seat in order to see whether an RHP could operate the 'left-hand' controls. He reported: "That was the wildest flight of my life. I never again attempted to pilot using the 'left-hand' controls."

In 1911 the Wrights installed a dual right-hand control arrangement in one of their machines so that a right-hand pilot could instruct pupils in the use of the right-hand controls. By that time the Wrights were well aware of the handedness factors involved.

That important item of aviation history provided a useful starting point for researching the evolution of the side-by-side 'flight-deck', with its strong hand and side preference characteristics, and the allocation of roll and pitch control to the hands and not to the feet. The Wright's method of control did not involve use of the feet until after 1912.
A detail point but nevertheless of some importance when establishing the origins of aviation control stereotypes was the 'Wright' movement of the principal control lever (roll control). As shown in fig. 3.5.3., this was usually at the pilot's right-hand and was pulled and pushed in the fore and aft plane to warp the wings and to turn the rudder so as to effect a turn to the left or to the right. A complete turn, according to Harris (1970) was not attempted until September 1904.

From the modern accumulation of control stereotype information it would be inferred that when the lever was pushed forward it caused a turn to the left. That assumption is correct even though there was little evidence published at the time of the earliest flights to establish the control lever/control surface relationship. Of greater importance, with respect to the relationship of the use of the pilot's two hands and the movement of the controls, was the use of a lever which moved in the fore and aft plane.

Wilbur Wright commented on the control system as follows:

"I think the error ('digging-in' in turns) is caused by the fact that the lever adjusting the tail moves fore and aft like that adjusting the front rudder (elevator) and that as I shove the left hand forward to maintain speed I instinctively tend to do the same with the other. I have noticed myself make this movement of the right hand in straight flight when a gust compels quick movement of the left hand."

Wilbur Wright's comment on the dangers of that type of control was echoed by a pupil who remarked on "the unnatural method of using the warping lever". Another pupil who, despite practice on a simulator, failed to grasp the correct relationship between the way in which the lever moved to effect a desired direction of turning; eventually in desperation he 'borrowed' an aircraft and attempted a solo flight. His inability to master the warping lever resulted in a crash and his death.
Another pioneer designer, Glen Curtiss, adopted a different arrangement of the primary flight controls. He used a yoke on the pilot's shoulders for roll control and a wheel mounted on top of a central column for rudder control. A turn to the left, for example, was achieved by the pilot leaning to the left and rotating the wheel anti-clockwise. In Santos Dumont's Demoiselle of 1908 wing warping was by a lever attached to the back of the pilot's jacket.

'Body' control was 'instinctive' because the pilot leaned towards the inside of the turn as if he were riding a bicycle. This was an example of a strong control stereotype from an earlier form of transport dominating the mechanical systems of aviation.

In the period 1908-1911 there were many different types of control arrangement tried by aviation pioneers. Bleriot, for example, in the monoplane in which he made the first flight across the English Channel, 1909, used fore and aft set wheels for the primary controls. The pitch wheel was to the right-hand which was opposite to that of the contemporary Wright machines.

1909 was also the year in which an important 'handedness' event occurred. This was the Commission Aerienne Mixte proposal that there be a 'keep right' rule when aircraft met head on and that the red and green navigation lights of ships be adopted for aviation.

Towards the end of this period the control of the rudder became a stereotype. This took the form of a pivoted bar operated by the pilot's feet so that the laterality factors of which hand should operate the rudder were no longer of importance.

Although not directly related to laterality the question of which way the rudder bar moves to effect a desired turn was one which was not settled for some years. Eventually the stereotype control arrangement became one in which the pilot pushed forward the foot on the side to which
he desired to turn. In other words, opposite in effect to the movement of the handlebars of a bicycle but similar in mechanical arrangement to the tiller ropes of a boat.

Why did the Wright Brothers install the engine of their basic aircraft design to the right of the medial? That question could not be answered with certainty because the evidence studied, including the Wright Papers, gave no positive explanation.

When the Wrights made their epic first flight they entered a new control environment and there were no 'aviation' traditions or habits which might have influenced their choice of engine position.

It was significant at the time that the Wright Brothers chose a pilot/engine relationship relative to the vehicle medial which was opposite to that of the contemporary automobile in which the driver sat to the right of the medial.

The Wright Flyer of 1903, and subsequent versions, had contra-rotating propellers so that they did not have to consider the effects of torque reaction which otherwise might have influenced the arrangement of the controls, the pilot's position and the location of the engine. (The effects of torque reaction are considered in detail in sub-section 3.5.5.)

There were no asymmetrical features of the Wright gliders; from which the first powered aircraft were developed.

The only explanation of the Wright layout of pilot and engine was to be found from descriptions of the engine and its controls. The engine was mounted in the aircraft so that it lay on its side with the induction and ignition systems uppermost and therefore accessible. The design of the engine was such that it had to lay on its left side which meant that if the controls were to be kept as simple as possible the pilot had to be positioned to the left of the engine close to the cylinder heads and not
on the crankcase side. see Fig. 3.5.4.

Having settled the relative positions of the pilot and engine, the Wrights then had to introduce asymmetry in plan because the right wings had to be greater in span to balance the weight of the engine.

When Sopwith constructed his version of the Wright design but using a different engine he placed the pilot to the right of the medial. From which it might be inferred that aerodynamically one side was as good as the other and only mechanical requirements or left turn preference on the part of the Wright Brothers were the progenitors of stereotype aviation practices which are described in sub-section 3.5.5.

Overall in this period, when there were only a few designs of aircraft and the annual exposure to the new element in terms of flying hours was small, it could not be said that there were strong hand and side preference factors. More likely, the way in which aviation practices and habits evolved was one of copying the way in which others had successfully coped with design problems. Therefore, if one placed the pilot on the left others were encouraged to do the same. If the first complete turn was round to the left then others would do the same. At the same time there was the influence of the competitive race track left-hand circuits; as used for the earliest aviation meetings.

The following references listed in this sub-section refer to the Bibliography and References appended to section 3.

McFarland's Wright Papers pp 269,469,471,919,1004 and 1159
Gibbs Smith pp 99 and 103
Josephy pp 132,153 and 157
Lewis pp 108,313,418,469,110,112,200 and 406
Longmore p.17
3.5.5

Hand and side-preference influences. 1914-1972

This sub-section considers the origins of the left-hand circuit rule for approaching airfields, the right-hand on the principal control practice and the principal pilot to the left practice.

The various originating factors are arranged approximately in chronological order from 1914 onward. However, the influences of the rotary engine with its gyroscopic effects, high torque propellers and the in-line engines with exhaust pipes on the right are dealt with first as their influence covered one of the most important formative span of years in aviation.

3.5.5.a

Rotary and in-line engines. 1914-1918.

The rotary engine with its gyroscopic effect was a significant mechanical influence on the design and operation of many aircraft types in the period 1914-1918. That hypothesis was considered in relation to the handling comments of pilots as recorded in the relevant literature.

The gyroscopic in association with the propeller torque effect produced a specific group of handling characteristics which were sufficiently marked to generate general comment about the dangers of flying some of the aircraft types fitted with high powered rotary engines. The following aircraft types had right-hand tractor airscrews; that is, when looking forward from the cockpit the engine rotated clockwise and the propeller 'screwed' its way through the air in the manner of a right-hand threaded screw:

Sopwith Baby, 1½ Strutter, Pup, Triplane and Camel
Vickers ESL
Of the foregoing right-hand tractor rotary-engine aircraft, the Sopwith Camel was the subject of many comments about its handling characteristics. The gyroscopic and torque effects which varied considerably with changes of engine speed had to be mastered by ab-initio pilots otherwise they did not survive many hours of training. The Camel was an aircraft used in great numbers and therefore it was inferred that its characteristics influenced the lateral practices of pilots which in turn influenced the formation of rules; among the more important being the preference for approaching to a landing in a left-turn or side-slip rather than to the right which, as part of a causal chain, reinforced the left-hand circuit. Evidence for the extent of the effect of the handling characteristics was obtained from Pudney (1964)\(^1\), Lewis (1967)\(^2\), Penrose (1969)\(^3\), Robertson (1970)\(^4\), Kermode (1944)\(^5\), and Setright (1971)\(^6\). However, the evidence studied did not make direct reference to any rules derived from the left-turn preference and it could only be inferred that the rotary engine with its clockwise airscrew was the origin of subsequent aviation practice.

To test the validity of the assumption concerning the rotary engined aircraft consideration was given to the general design of contemporary German aircraft. Many of these had in-line engines from which the exhaust pipes discharged to the right. Because of the exhaust-to-the-right arrangement one historian, Alex Imrie, had postulated that the preference the German pilots had had for leaning to the left and thereby scanning the landing area to the left and turning to the left was to avoid the stream of exhaust smoke along the right side of the cockpit. It was a reasonable construction of circumstances which when considered against other evidence, such as the preference for climbing into the cockpit from the left side, suggested that the German pilots were as left-side and turn preferring as their British counterparts.
Taken together the German and British mechanical factors gave the same result; the preference for the left-turn and the left-hand circuit and approach to land as evidenced particularly by the Schnieder Trophy racing circuits 1913-1931 which were all run anti-clockwise.

3.5.5.b
Other factors considered for the period 1914-1972

1916. Fokker Monoplane El had an 'ambidexterous' double grip joystick and was therefore, similar to the type usually fitted to British aircraft at that time.

The Zeppelin airships of this period had a control car which was arranged with instruments and controls with positions for the elevator operator to the left of the medial and for the executive officer to the right.

1917. The twin-engined Gotha bomber had the pilot's position to the left of the medial. A similar arrangement was used on the AEG bomber. Mounting of interplane airspeed indicators reflected side-preference. The Lloyd CV had the airspeed indicator fixed to an interplane strut on the left of the pilot which, along with the left-hand circuit, was another reinforcing factor to the general left-side and turn preference of aviation.

1918. The Fokker E5 had a pilot's control column which could only be held effectively by the pilot's right hand. The Hannoveraner biplane of 1918 had a machine gun to the right of the cockpit medial with controls to the left. The Junkers D1 had a right-hand only joystick incorporating throttle levers for use by the left hand. The Fokker DV11, a most successful aircraft of which many were built and which incorporated many excellent ideas, also had a right-hand only joystick.

1919. Large British multi-engine aircraft built from 1917 onwards and used extensively during 1918 and for civil pioneering flights from 1919 onwards followed automobile practice and had the pilot's seat to the
right of the medial; the opposite of the German arrangement. Notable 'right-hand-drive' types were: Vimy, O400, V1500 and the Atlantic.

Consideration was given to the influence of the Nayy on the design of the large British aircraft which were used first by the Royal Navy Air Service. The naval preference for the senior position to the right of the medial, as described in section 3.1, may have been an important influence on this aspect of aircraft design.

In 1919 international agreement was reached that aircraft should keep to the right when flying along airways or towards navigational marks. 1922. The Fokker F11 originally had the pilot's position to the right of the engine but in order to comply with international regulations concerning keeping to the right of an airway, the pilot's position was moved over to the left. In contrast British aircraft retained the principal pilot's position on the right.

1927. Lindbergh's transatlantic Ryan monoplane had a sighting periscope on the left side only which provided further evidence of the left-side and left-turn preference in aviation. ref. McDonough (1966). The Levasseur PL-8, ref. McDonough (1966) provided evidence of a significant arrangement in the history of handedness in aviation because the pilot's seat was to the left with the navigator to the right of the medial.

1930. In the control car of the airship R101 the elevator coxswain was to the right of the helmsman whereas in the Zeppelin airships the elevator man was on the left; as described supra.

In the Graf Zeppelin it was observed that the airship commander stood to the right of the control position medial thereby deliberately or by chance following the naval right-side precedence custom as described in section 3.1.

In this decade aircraft carriers were designed with the control island on the right.
1940. By this year the majority of British multi-engine aircraft were arranged with the principal pilot's seat on the left.

1942. The Helleliz, which was a twin fuselage aircraft, had the pilot's position in the left-hand fuselage of the two. The design was such that as far as could be ascertained there were no aerodynamic or mechanical reasons why the pilot could not have been in the right-hand fuselage. Although in an asymmetric aircraft of this period built by Blohm u Voss the pilot sat to the right of the single engine, a position dictated by aerodynamic and mechanical considerations.

1945. The R & S Desford had a dextrad control column hand grip with brake lever which was very difficult for operation by the left hand; on many British aircraft of the 1940s the brake-lever on the control column was operable only by the pilot's right hand.

Sub-section 3.5.5.

References to bibliography

1. Fudney (1964) Pages 5, 7
2. Lewis (1967) Page 101
5. Kermode (1944) Page 196
3.5.6

Research into human laterality in aviation

3.5.6.a

Human laterality

Beaty in 1969 summarised many of the more significant aspects of human laterality in the aircraft man/machine interface. Reference was made by Beaty to experiments with aircrew in which it had been observed that a number use their left hands unconsciously for doing certain things. It was concluded that aircrew, although a special population, were typical of a general population. Beaty also referred to the general observation of physiologists and psychologists on the laterality confusion of many pilots who though they were classified as right-handers confused left and right to varying degrees in varying situations. To quote from Beaty, p.153: "Some mix east and west, try to unscrew nuts clockwise or have continual difficulty over times in different longitudes...."

Gerhardt's research at the Institute of Military Psychology in Norway, ref. Beaty ibid, p.153 et seq, provided significant comment on human laterality in aviation. As with the research of Clark and Annett, Gerhardt found that 'right and left handedness' was too much of a generalisation because a laterality pattern might be present to some extent in people who had no overt handedness characteristics. There was a tendency among some people, who declared themselves to be clearly handed, to have established a set of careful actions which enabled them to conform to their 'declared' handedness. Only when they were surprised or when under stress would they revert to their true laterality with the result that they could confuse left and right.

Gerhardt's observations related particularly to the behaviour of aircraft pilots under stress. He had found connections between laterality and maladjustment in military pilots. One example quoted by Beaty, ibid,
referred to a pilot who had the handedness characteristic of ambidexterity. However, the subject had been left-hand preferring as a child but had subsequently practised many manual skills with the right hand; for example, handwriting. Only after he had been selected, medically examined and trained as a pilot was it shown that he had to refer to his wedding ring in order to identify left and right when instructed to turn in a given direction.

Another aspect of laterality as part of a pilot's reaction to perceptual stimuli are the scanning patterns used for visual lookout for conflicting traffic. The research considered the possibility that in a hypothetical unoccluded forward sphere of vision a pilot scanned in accordance with a pattern which reflected innate and learnt directionality. Essentially, if the dextrad writing form dominated then the view-ahead would be scanned 'line-by-line' from top-to-bottom and from left to right. In section 1.10, et. seq, in which directionality in general was considered, the scanning diagonal bottom-left to top-right formed the basis of studies and conclusions by researchers into perceptual behaviour, particularly Arnheim, Gaffron, Klee, Fritsch, Noton and Stark. Did that upward, left-to-right scanning pattern apply to the pilot's visual outlook?

Noton and Stark (1971) emphasized the variety of scanning patterns used by different subjects. The eye-marking technique used by the UK Road Research Laboratory, as noted in section 3.3.11., provided no evidence of significant directionality in car driver's scanning patterns. Rich et al (1972) studied both experimental set scanning patterns and the random patterns used by pilots in a 'skewed' arrangement of visual-arcs which arises from a pilot on the left of the aircraft's medial. They give no evidence of pronounced directionality in scanning; presumably because the configuration of the vehicle environment interface and the directions from which conflicting aircraft were most likely to appear, imposed a set
Typical areas of view subtended by the pilot's eyes when he is in the left-hand seat. Fig 3.5.6.
of scanning patterns which dominated any innate or learnt behaviour.

One example of the way in which the configuration of the control position influenced the visual scanning pattern of the pilot is illustrated in Fig. 3.5.6: which shows the comparative areas of vision subtended by the pilot's eye-point when he is in the left-hand seat. From the left-hand position, conflicting aircraft which appear to the right of the aircraft medial will be more difficult to detect than those which appear to the left of the medial.

Rich et al, p.19, questioned the applicability of the "right-hand rule"; as stated in the USA airways regulations and in those of other countries. The rule gave aircraft on the right, the aircraft seen with most difficulty, the right-of-way. This rule derived most likely from the marine rule-of-the-road at a time when arcs-of-vision were equally good to either side of the medial. The rule had not been amended to conform to the principal pilot on the left practice which had become standard for many of the world's aircraft; particularly passenger transports.

3.5.6.b Laterality and Accidents

Beaty, ibid, cited eight or nine civil aviation accidents in which human laterality might have been a factor.

A feature of many aircraft accidents has been the effects of pilot stress and fatigue which in conjunction with a series of incidents, none of which in isolation was serious, resulted in disaster. Under stress or fatigue, covert laterality patterns might dominate a pilot's behaviour thereby inducing him to turn the aircraft in the wrong direction, incorrectly set the vertical speed or move controls in the wrong direction. Also, under stress, a pilot might transpose numbers on some vital input; for example, setting the altimeter reference level. ref. Rolfe (1969...)
Some of the more important examples of confusion between left and right occurred with the identification, from instrument readings, that an engine on one side had failed followed by confusion of action whereby the wrong engine was switched off.

3.5.6.c
Lateral nomenclature in aircraft.

The influence of nautical terminology was most apparent with the use of 'port' for left and 'starboard' for right by British aviation. Left-side and right-side were used by other countries and eventually were used more frequently in Britain. Under the stress of aerial combat, particularly in bomber aircraft when attacked by fighters, a 'clock' system was used in which 12 o'clock represented a position directly ahead; this was particularly useful when orders had to be passed to gun-turrets which could train through wide-arcs and on occasions were pointing astern so that the gunner's right-side was to the left-side of the aircraft.

Port-engine and starboard-engine were usually adequate for twin-engine aircraft but with the advent of four engines it became customary to number the engines from left-to-right, looking forward, so that on the far left was No.1. In section 3.1.5 reference was made to the social precedence order of No.1 to the right and to the allocation of No.1 to the right-hand side of ships so that aircraft engine numbering did not appear to have been influenced by that particular tradition.

For a few years, in the late 1940s, British aircraft designers introduced an example of lateral confusion when they positioned the flight-engineer and his controls facing astern so that his left hand was to the right-side of the aircraft and all the controls and instruments were spatially a mirror image of the arrangement of the parts of the aircraft to which they referred.
Conclusions and Summary of section 3.5.

The sword and whip practices of Section 3.2 were tested to see if they provided one of the origins of aviation hand and side preferences practice.

The Wright Brothers devised a system of primary control which appeared to be unrelated to other forms of transport; as described in 3.5.4 The right hand was given the greater skill task and not the left so that the practice of allocating the primary control of horses to the left hand was not an influence on aviation practice. Alternative methods of control used by those who followed the Wright Brothers showed many variations and it was not until about 1913 that the dominance of right-hand-preference finally dictated the right-hand on control column stereotype. This right-hand dominance could not, therefore, be said to be the result of the control methods used in non-aviation forms of transport.

The Olympic left-circling practice was tested as an origin of aviation turning and side preferences.

The literature of early flying suggested that because the Wright aircraft had the pilot to the left of the medial he preferred to make a turn to the left. Harris (1970) referred to the fact that on the 20th September 1904 the first full circle was attempted by Wilbur Wright and it was made anti-clockwise, i.e. Olympic. The Olympic direction was a possible reason for Wilbur Wright's left-turn decision but no evidence was found to substantiate it. The Olympic direction used for horse and motor racing might have been an influence but chance may have played an equal part. Only the displacement of the pilot to the left of the medial gave an acceptable reason for the left-turn decision.
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wind relative to the starting line so that neither chance nor custom could be said to have influenced the circuit direction. However, subsequent circuits in France were usually run anticlockwise as were the majority of events in other parts of the world, the UK excepted, prior to 1914. In the UK the important meetings at Blackpool and Doncaster were run clockwise and the regulations issued beforehand by the organisers specified clockwise without reference to the wind direction.

A relevant quotation from 1909 is "French pilots prefer to make their circuits in an anti-clockwise direction, that is to say, they would rather turn to the left when rounding a mark than turn to the right. This is of course, a mere prejudice, resulting from custom".

The effects of aircraft configuration, rotary engines, propeller torque and gyroscopic couples were detailed in section 3.5.5. Those effects in combination with the right-hand on the primary control and the left-turn preference reinforced the left-hand circuit preference.

The marine rule-of-the-road, first considered for aviation in 1909, was adopted as a regulation in 1919. It introduced the contrast between aviation and marine side preferences and practices. At sea the rule related to the custom of the principal officer standing to the right of the medial and to the keep-right rule in channels but in the air it eventually became confused when the principal officer was to the left of the medial.

The stereotype right-hand on stick arrangement influenced the design of aircraft in which the pilot sat to one side of the medial.

Overall the individual factors which influenced aviation practice produced a preference to scan to the left, circle to the left, lean to the left, turn to the left and fly right-hand on the primary control. However, in those aircraft types in which the pilot sat to one side of the medial, usually on the left, these factors had less significance and the operating environment of modern transport aircraft was more symmetrical in its effect on the pilot's behaviour and on the arrangement of the control position.
The helicopter provided a clear example of a complete reversal of what at one time was a well established stereotype. This was the positioning of the principal pilot to the right of the medial.

One of the three principal characteristics of laterality in aviation was the study of the lateral characteristics of pilots. Human laterality in aviation as a population characteristic was little different from that of other highly trained skill groups. Training and adaptability to the special control skills overcame most handedness problems. However, reversion under stress to true laterality remained a particular problem.

As with other forms of transport studied, aviation did not provide any clear evidence of pronounced directionality in scanning patterns or any significant influence from the dextrad order of writing and printing other than the use of lateral definitions for components based on left-to-right directionality; i.e. engines numbered from left to right looking forward and not, as in ships stations and compartments, from right to left.

Finally, in this summary of the aviation laterality factors, is the conclusion that hand and side preference factors which are significant in aircraft with a pilot on the centre line are of less importance when the pilot is to one side of the medial. In the side-by-side flight deck each of the two pilots has to learn to adapt to a visual scanning pattern appropriate to the side of the aircraft on which he is sitting and in some respects this is analogous to the car driver's visual task when driving either on the left or the right of a car.

Inside the flight-deck the controls and equipment are arranged in a mirror image pattern about the medial but in a number of different lateral sequences; depending on their function. For example, the primary controls carry buttons and selectors on the hand grips arranged mirror image to enable the pilots to operate them with the hand most used on the control; that is the outboard hand as shown in Fig. 3.5.7. The
primary instrument panels, one for each pilot, are to an identical arrangement of instruments. The principal engine control levers are arranged in topographical relationship to the engines with engine No.1 controls on the extreme left and with the instruments for each engine in related vertical rows. In effect pilots have to learn and adapt to two versions of the aircraft type they fly: one version has the controls basically arranged for left-hand on primary control, the other version is arranged so that the pilot operates the engine controls with his left hand and the primary control with his right.
Section 3.6

The influence of human laterality in modern and future control interfaces.

3.6.1

Introduction

3.6.2

Tactile control panels

3.6.3

Specific types of modern and future control interfaces:

3.6.3.a Ships
3.6.3.b Automobiles
3.6.3.c Railway vehicles
3.6.3.d Aviation and space vehicles

Section 3.6 Illustrations.

3.6.3.A Steering and control console in a modern ship
3.6.3.B Modern railway interface
3.6.3.C Right-hand only aircraft primary control lever
3.6.1
Introduction

In section 2 reference was made to the right-hand-world of artifacts and human behaviour and to the ways in which the RHW had changed and might change in the future. The inference was made that in the future the RHW would not be as extensive as it is at present because with each new generation of men, artifacts requiring strength of limb to operate were becoming fewer in number. Only those artifacts which required coordination of hand and eye would continue to contribute to the RHW.

The keyboard, push-button and touchwire type of interface was now a feature of many vehicles and quasi-vehicles and the number of vehicle types equipped with large levers and wheels, requiring manual effort, was declining. The advent of electric and electronic control systems was rapidly changing the overall look of man/machine interfaces. Modern control techniques enabled a greater number of control functions to be grouped on one panel in front of one operator and to be duplicated at other locations in a vehicle.

3.6.2
Tactile control panels

The keyboard and push-button type control panels are less affected by human laterality factors because of their limited size and accessibility equally to each hand. Any laterality influence which may be present at the control interface, because of an operator's behavioural characteristics, is likely to be small and will be eliminated in time by adaptability and training.

Of some possible significance are the relationships between operator behaviour which has been influenced by the dextrad forms and the topography of a modern tactile control interface. An operator might have strong conceptual patterns based on the dextrad forms, such as the printed words,
handwriting, the alphabet and the numeric sequences. These conceptions may not necessarily match all the possible topographical arrangements of a tactile interface some arrangements of which are as follows:

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dextrad  dextrad  descending  ascending  ascending  anticlockwise  and  clockwise

Plus the sinistrad equivalents of the above

3.6.3.a
Modern and future ships' control interfaces

Research into the design of modern and future ships' control interfaces showed that the hand and side preference factors which were considered in section 3.1 were still apparent but that detail control design was changing rapidly to match the ergonomic and industrial design standards of other forms of transport. In addition, the influence of human laterality and the need to make provision for human handedness was becoming of less importance.

The principal laterality factors which were considered in 3.1 are no longer of such significance on the control bridge of a modern ship and are likely to be of even less significance in future designs. When mechanical considerations limited the number of sets of primary controls at a command station to one, the influence of human laterality and side precedence and preference was usually clearly apparent. In contrast, modern systems for remote control of primary functions, such as steering and power, can be multiplied so that the operators are able to control a ship from the position which affords the best information for a particular operating mode. As an example, on the bridge of a vessel which makes
frequent departures and arrivals the master is given a control panel on each wing of the bridge in addition to one at the principal control station on or close to the medial of the bridge.

Fig. 3.6.3.A shows the bridge steering and control console of a modern warship. The operator (helmsman) has controls and instrumentation arranged in a way similar to that of an aircraft. The individual control levers and switches can be operated by either hand so that human lateral preferences are not necessarily significant; particularly as both the steering wheel and the main power control levers require only small muscular effort to operate. The control position illustrated is becoming typical of modern ships and those of the future. It represents an interim stage towards a completely push-button interface in which, with the exception of any adherence to dextrad forms, exhibits only minor influences of human laterality. Had this integrated control position been attempted as a design in an era before the development of servo assisted controls the influence of human laterality might have been more obvious.

Another factor of increasing importance is the provision of controls, instruments and navigation lights which in effect interchange bow and stern to facilitate docking when loading and off-loading vehicles.

Whatever the level of handedness or of side precedence and preferences existing in conventional vessels, it is either reversed or obscured in modern vehicle ferries which can be operated with equal facility in both directions. All that remains is the convention that the direction in which the master and the helmsman face and in which the ship is moving is the reference for the convention of left and right.

3.6.3.b
The automobile

The increasing use of control systems which simplify the operator's manual tasks, so that there are sometimes only three primary controls,
Fig 3.6.3A

This illustration shows the helmsman's control desk of a modern warship.

The large engine control levers, the equivalent of the engine room telegraph, are set at the operator's right hand.

The steering control is on the operator's medial.

The secondary controls are at the operator's left hand.
results in a corresponding simplification of the laterality factors within the operator's ergosphere. The remaining laterality factors of significance are those arising from the rule-of-the-road and the dependent asymmetric location of the driver's position relative to the vehicle medial.

The continuing use of bi-directional highways and the requirement that operators keep their vehicles to one specified side of the track medial is associated with the economic requirement that the driver shares the control position with a passenger so that symmetrical arrangements of the control position are rarely used.

These are factors which have been reviewed in section 3.2 and were primarily concerned with the operation of cars on bi-directional tracks. In modern automobile operation and in the future, the more representative situation is that of the motorway and its special system of entrances and exits. These provide a special set of modern operating conditions which, in many respects, are different from those of urban and rural bi-directional-road, driver/vehicle situations.

The clearly defined separation of opposing direction traffic on motorways introduces a special set of lateral factors, particularly those relating to visual perception.

In Britain and other drive-on-the-left countries, the visual data which gives a driver cues from which to predict the path and performance of his vehicle tend to appear in the left visual arc. The opposite set of conditions applying in drive-on-the-right countries.

Overall on a motorway a driver is in an asymmetrical visual perceptual situation. These visual cue lateral influences are in themselves derived from the appropriate rule-of-the-road. However, the rule-of-the-road, as considered in section 3.2, was derived more from human laterality as an influence rather than from difference's in attention to the left-visual field compared with the right-field.
Modern and future railway vehicle control positions

A modern control interface for a high-speed train is illustrated by Fig. 3.6.3.B.

Of significance to this research is the location of the primary power/speed control lever to the driver's right-hand and the brakes control lever to his left-hand; thereby conforming to the existing practice for Europe and to the earlier steam locomotive practice of Britain and France in which the driver operated the power lever with his right-hand. Also of significance is the location of the telephone which can be reached by the operator's right-hand but not so easily by the left-hand. Overall the control position illustrated retains the concept of handedness as a major influence on the layout of the principal controls. In other details the design of the interface in Fig. 3.6.3.B reflects the symmetry which is possible when the operator's seat is on the vehicle medial. Placing the driver on the medial is a fundamental departure from previous railway control position stereotypes. (ref: Coombs (1972). 'Visual Perception and High-speed Trains' jnl: Modern Railways Dec 72)

There is now a tendency to design trains in which the operator is outside the control loop. The control interfaces of the future may consist only of monitoring lamps so that there will be little evidence of the influence of human laterality.
3.6.3.d
Aviation and space vehicles – future control position design

The aircraft and its lateral factors, as described in 3.5, included a significant number of controls and operating practices which reflected human lateral preferences.

Duncan (1969) and others illustrate spacecraft control positions with control input devices and data displays similar to those of contemporary aircraft. It is apparent that well-tried instrument and control techniques have been used as much as possible so that the predicted levels of reliability are high enough. As an example the main instrument display panel of the Mercury spacecraft is equipped with aircraft type instruments and tactile input devices.

The laterality factors in the Mercury, Gemini, Apollo and the Apollo lunar-exursion-module are little different from contemporary aircraft man/machine interfaces. Significantly, lateral preference and precedence, whereby the senior operator is to the left of the medial, follows aircraft practice.

Many of the data displays and the alphanumeric tactile inputs are arranged in a dextrad order with the result that even with the latest type
of vehicle man continues to be influenced by his right-hand-world even when preparing for journeys of millions of miles away from earth.

Apart from spacecraft there are control interfaces designed for use with modern vehicle and quasi vehicle systems which retain the influence of RHP. As an example there are CRT type control stations with a joystick primary control lever positioned and shaped so that it is operable only by the right hand. These are examples of the influence of the RHW being stronger than man's design ability to produce ambidexterous control interfaces. Fig. 3.6.3.C shows an aircraft primary control lever which is operable only by the pilot's right-hand.

Overall, with the gradual elimination of manual-effort type controls, modern and future control interfaces are becoming less handed with the possible eventual result, as illustrated in Fig. 2.2.C of section 2, that the future world of technology and its artifacts will be less right-skewed.
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4. Pilot Experiments and conclusions

4.1 Pilot Experiments

4.1.1 Introduction and objectives
4.1.2 Description of pilot experiments
4.1.3 Pilot experiments reported on in Appendices A and B
4.1.4 Summary of pilot experiment results
4.1.5 Future studies:
   Appendix A
   Environmental psychology
   Sensory invariance

4.2 Summary of Research and Conclusions

4.2.1 The influence of human laterality
4.2.2 Studies of specific vehicle types
4.2.3 The sword factor
4.2.4 The Olympics
4.2.5 The Right-Hand-world
4.2.6 Quasi-vehicles
4.2.7 Visual perception in the man/machine interface
4.2.8 Principal causal chains
4.2.9 Freedom of designer's choice
4.2.10 The choice situation and the negative approach
4.2.11 The future

Appendix A: crane controls experiment.
Appendix B: space vehicle controls experiment.

Illustrations:
Figs. 4A1 to 4A5 and 4Aa to 4Ag  Illustrations for Appendix A
Figs. 4B1 and 4B2  Illustrations for Appendix B
4.1 Pilot Experiments

4.1.1 Introduction and objective

In 1.9.2 reference is made to the possible influence of the dextrad form during the conception of a control interface: particularly the possible influence of the serial order of numbers, the alphabet and the directionality of the clock; all of which have been the subject of studies referred to in the relevant literature and which are summarised in 1.8 of this thesis.

Two pilot experiments were constructed: one was tried with a group of primary school children and the other given a limited evaluation. The objective of this type of experiment being to determine the extent to which experience of dextrad forms influences the conceptual actions when asked to 'design' a control position.

4.1.2 Description of pilot experiments

Two pilot experiments were constructed to check the validity of the proposed procedures for determining the extent to which the dextrad forms might influence the conception of a control interface. The two pilot studies described in the appendices to this section are:

A. Crane Controls Experiment with Primary School children arranging four control items on a simulated crane control panel.

B. Space Vehicle Controls Experiment with adult subjects arranging four control modules on the simulated control panel of a space vehicle.

These pilot experiments are intended as pointers to full scale testing using statistically acceptable population numbers from which it might be possible to determine quantitatively the extent to which human laterality
in general and the dextrad forms in particular are an influence on the way in which a subject conceptualises a vehicle control interface.

4.1.3
Pilot Experiments

The specific pilot experiments are reported on in Appendices A and B of this section.

4.1.4
Summary of pilot studies results

In the Crane Controls Experiment, Appendix A, the significant results were:

a) None of the subjects arranged the pattern of control items in accordance with the 'expected' pattern based on the serial left-to-right 1,2,3,4 form.

b) A preference for starting an arrangement of control items at the left side of the control panel matrix which might indicate, in full scale testing, the influence of the dextrad form.

c) Although result b) might be an indication of the influence of the dextrad form on the conceptual behaviour of a subject it did not fit result a).

d) Overall, the 16 cell matrix used for the experiment imposed a limitation to the number of possible arrangements of control items.

The Space Vehicle Controls Experiment, Appendix B, was similar in concept to that of Appendix A but used adult subjects and relied less on the simulation of a real control position situation. The tests were limited in number and were intended only to check the validity of the methodology for future large scale tests.
4.1.5
Future studies

The following recommendations are made from analysing the Crane Controls Experiment:

1. A 49 cell matrix might be better than the 16 cell matrix because it provides a subject with two axis of symmetry and greater freedom of choice of direction when arranging items in linear form.

2. In addition to recommendation 1, subjects could be constrained to starting an arrangement of items from the centroid of the matrix so that they have eight possible directions along which to extend linear groups.

3. Control experiments could be as follows:
   a. As the present experiment but using coloured squares in place of simulated controls with subjects using the preferred-hand only.
   b. As above, with subjects using the non-preferred hand only.
   The two control tests might provide an indication of the extent to which non-control interface patterns were influencing a subject's preference.
   c. As the present experiment but using a group of adults who although not human factors people have some knowledge and experience of control interfaces.
   d. As above, using the preferred-hand only.
   e. As above, using the non-preferred-hand only.

4. Recommendations for analysing the results of the foregoing proposed experiments:
   a. The relationship between controls arrangements and a subject's experience of spatial relationships, such as drawing and design might give useful data.
   b. The relationship between controls patterns and the dextrad form expressed as the resultant of symmetry and order as one influence and the dextrad forms as the other influence.
c. In experiments with children the relationship between resulting patterns and the ability to read.

Environmental psychology

Human laterality and the conception of spatial and temporal relationships was considered as a possible area of future research and as an extension of existing studies in environmental psychology. Professor Lee's, ref Lee (1973) research into the relationships between subjective distances and directionality and their true values could be the foundation of specific studies of human lateral preferences and directional preferences when controlling a vehicle. Furthermore, such research might provide data from which to judge commonly expressed opinions about human left-hand and right-hand preferences which at present are listed as apocryphal.

Sensory invariance

Future research into the influences of human laterality when in control of a vehicle might include a study of the effects of sensory invariance. Unanswered in the literature researched was the question: in a sensory invariant environment did a subject experience any bias towards one side when conceptualising a spatial reference?

If experiments could be conducted with subjects trained or instrumented to assess tendencies to make turns or circlings in a particular direction they might provide significant facts about side and turn preferences in general.

It was noted that the majority of research into sensory invariance and its effects was concerned with the mental stability of the subjects and was not concerned with simple trends such as any tendency for a subject to deviate in a particular direction from a straight line when walking or when controlling a vehicle when deprived of the usual aural, visual and vestibular cues.
The histories of human experience in a partly sensory invariance state did not provide any conclusive evidence. There were records available of the experiences of subjects who had accidentally been projected into a sensory invariant environment; such as explorers in a featureless territory deprived of orientation cues. Overall, man's total experience of accidental sensory invariant situations was small compared with the total human experience or orientation using a single orientating cue; such as a star. Throughout the history of man, accidental exposure to a sensory invariant environment was rare and those that had had the experience had left few analytical records.

Therefore future research might be directed at trying to separate the effects of hand and side preferences from the total behavioural pattern of subjects at a control interface by using the established techniques of investigating control skills in situations having significantly reduced orientating data and in extreme degrees of sensory invariance.
### SUMMARY OF PRINCIPAL FACTORS

#### EXAMPLE

<table>
<thead>
<tr>
<th></th>
<th>LEFT</th>
<th>MEDIAL or STATISTICAL</th>
<th>RIGHT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MAN</strong></td>
<td></td>
<td></td>
<td>Majority having characteristic of right-hand preference.</td>
</tr>
<tr>
<td><strong>Water craft with man using pole-like artifacts</strong></td>
<td></td>
<td></td>
<td>Majority used in right-hand position.</td>
</tr>
<tr>
<td>Steering artifacts:</td>
<td></td>
<td></td>
<td>Majority mounted on right-side.</td>
</tr>
<tr>
<td>Steering board (Northern longships)</td>
<td></td>
<td></td>
<td>Exceptions noted in 3.1.</td>
</tr>
<tr>
<td>Tiller and shipstaff</td>
<td></td>
<td></td>
<td>Vessel's medial.</td>
</tr>
<tr>
<td>Steering wheel (c1700 onwards)</td>
<td></td>
<td></td>
<td>Vessel's medial.</td>
</tr>
<tr>
<td>Various customary side-preferences for ships' control and working equipment</td>
<td></td>
<td></td>
<td>As listed in 3.1.</td>
</tr>
</tbody>
</table>

#### ANIMALS AS VEHICLES

<table>
<thead>
<tr>
<th></th>
<th>Left-hand for primary control</th>
<th></th>
<th>Majority held in right-hand.</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Primary control</strong></td>
<td></td>
<td></td>
<td>Majority used in right-hand</td>
</tr>
<tr>
<td><strong>Implement and weapons</strong></td>
<td></td>
<td>(control position on medial)</td>
<td>Central position to right c1850-1850</td>
</tr>
<tr>
<td><strong>Land vehicles with draft animals</strong></td>
<td>Left-hand for primary control</td>
<td></td>
<td>Primary control at right-hand.</td>
</tr>
<tr>
<td><strong>Secondary control and implements</strong></td>
<td>Left-hand for primary control</td>
<td></td>
<td>Symmetrical arrangements about the median described in 3.6.</td>
</tr>
<tr>
<td><strong>such as ships</strong></td>
<td></td>
<td></td>
<td>Central position on right c1900-1930</td>
</tr>
<tr>
<td><strong>Railway vehicles</strong></td>
<td></td>
<td></td>
<td>Examples of both left-hand</td>
</tr>
<tr>
<td><strong>Primary control</strong></td>
<td>Left-hand for primary control</td>
<td></td>
<td>Primary control on medial.</td>
</tr>
<tr>
<td><strong>Primary controls and control position from about 1850 to be found on left as well as right depending on the particular practice of individual railway companies in different countries. (Details given in 3.4.)</strong></td>
<td></td>
<td>Primary control at right-hand.</td>
<td></td>
</tr>
<tr>
<td><strong>Modern railway vehicle control position and controls</strong></td>
<td></td>
<td>Symmetrical arrangements about the median described in 3.6.</td>
<td></td>
</tr>
<tr>
<td><strong>Automobiles</strong></td>
<td></td>
<td></td>
<td>Central position on right c1900-1930</td>
</tr>
<tr>
<td><strong>Control position from about 1930, with exceptions as noted in 3.3, related to rule-of-road so that there are drive and right-hand drive cars.</strong></td>
<td></td>
<td>(Examples of both left-hand and right-hand designs)</td>
<td></td>
</tr>
<tr>
<td><strong>Aircraft</strong></td>
<td></td>
<td></td>
<td>(Examples of both left-hand and right-hand designs)</td>
</tr>
<tr>
<td><strong>Wright gliders (millennial)</strong></td>
<td>Symmetrical arrangements of machine</td>
<td></td>
<td>Examples of both left-hand and right-hand designs</td>
</tr>
<tr>
<td><strong>Wright 1903 powered aircraft control position</strong></td>
<td>Engine offset to right</td>
<td></td>
<td>Primary control at right-hand.</td>
</tr>
<tr>
<td><strong>Primary control</strong></td>
<td>Secondary control at left</td>
<td></td>
<td>Primary control for right-hand.</td>
</tr>
<tr>
<td><strong>Subsequent evolution of aircraft control positions for one pilot in smaller types of aircraft</strong></td>
<td>Left-hand on throttle</td>
<td>Control position on medial</td>
<td>British practice c1916 to place pilot on right.</td>
</tr>
<tr>
<td><strong>Control position to one side types</strong></td>
<td></td>
<td></td>
<td>Second pilot on right.</td>
</tr>
<tr>
<td><strong>Two pilot control positions from c1930</strong></td>
<td>Principal pilot on left</td>
<td>Bilateral symmetry of cockpits</td>
<td>Aircrafts carrier control island on right.</td>
</tr>
<tr>
<td><strong>Olympic anti-clock circling tradition as an influence</strong></td>
<td>The universal left-hand</td>
<td>Airfield circuit</td>
<td>Principal pilot on right to suit mechanical convenience</td>
</tr>
</tbody>
</table>

#### LESS EMPHASIS ON LATERALITY FACTORS
4.2
Summary and Conclusions

4.2.1
Influence of laterality

The influence of human laterality on the design of vehicle and craft control positions, arrangements of controls and the rules governing their conduct within the operating environment was apparent with the majority of cases examined. The degree of influence, varied from vehicle type to type. With some, the degree of influence was defined clearly but with others it was sometimes hidden by other factors. The older or longer established forms of transport usually exhibited the most evidence of human laterality; particularly in the control interface environment. More recent forms included a greater influence of laterality on the rules governing the operating environment because of the general increase in density of traffic. Increasingly the man/machine interfaces of the different types of transport have tended towards less emphasis of the human laterality factors as levers, wheels and other inputs requiring significant muscular effort were replaced by simplified and concentrated 'low-effort' tactile interface units: ref. 3.6.

4.2.2
Specific vehicle studies

The evidence gathered to define the extent of human laterality both as a physiological and as a psychological factor, included a variety of specialised studies but it was nevertheless, bounded in its implication by the specific observation concerning handedness which emphasised that subjects exhibited different hand preferences and degrees of laterality for different skills in the man/machine environment. That is why the studies of specific vehicle and craft control interfaces were, in general,
limited to the primary controls and to the principal operating factors.

4.2.3. Sword factor

The most significant human factor, because it came early in the history of man and his artifacts, was the sword-in-the-right-hand from which depended a chain of customs and associated practices governing social customs and precedences, military etiquette and ceremonies.

Another important side preference origin was that of the horse rider when holding equipment in one hand, such as a sword, with the left hand used primarily for control of the animal.

4.2.4 Olympics

The left-circling Olympic athletic events provided another origin from which depended many existing land, sea and air rules-of-the-road. However, land transport side precedence and preference was not as clearly defined as sea and air customs and rules because of the conflict between the old rules derived from the armed horseman and the rules devised to suit the most convenient method of operation.

4.2.5 Right hand world

A study of artifacts in general, to determine the origins of vehicle control practices and side and hand preference, did little more than record the extent of the influence of the right-hand-world.

4.2.6 Quasi-vehicles

As a bridge between non vehicular artifacts and vehicles some artifacts were described as quasi-vehicles, the plough and the piano-forte for example, and their man/machine interfaces were examined.
Similarly the psychology of interpersonal behaviour was used to bridge the studies of non-transport man/machine interfaces. No conclusions were reached on this aspect of the research, primarily because the concept of a quasi-vehicle in an operating environment and the associated behavioural factors could not be referred to any specific studies in the literature.

4.2.7
Visual perception in man/machine interfaces

The visual perceptual task of an operator in a control interface could not be limited to one set of unique conditions; neither could it be described in general terms. Both spatially and temporally, the visual environment contained a variety of cues not all of which could be described in terms of an operator's scenario.

The transitional phase between the holistic view and the view in which an operator scanned the features of both figure and ground could not be described in terms of a specific man/vehicle interface without involving many assumptions and a stereotype operator with a stereotype scenario of visual perceptual behaviour. Therefore it was not practicable to assign specific research of eye-marking patterns, interpersonal behavioural sets and body-image factors to a specific set of control actions in a particular type of vehicle.

The man/vehicle interface for which there was the largest human experience available to research was the automobile. None of the extensive research of automobile driving factors, however, revealed pronounced directionality. Neither did the reports of eye-marking research, the influence of directionality from other areas of human behavioural research nor the influences of directionality in sensory/motor skills in general, change the concept that the automobile driver's set of behavioural characteristics was primarily one of adaptation of visual perception to a great number of cues presented equally in the
left and right visual fields. This was reported upon in 3.3.

4.2.8
Principal causal chains

The research established a number of causal chains, some of which could be defined clearly by the evidence which was available and others which were classifiable only as conjectural.

The preferred side or hand was retained by successive generations of operators throughout the evolution of the different branches of the dependent artifacts including vehicles. At each point in time where man had to continue a handed skill he was faced with three different actions from which to choose: one, to continue with the familiar stereotype or tradition; two, change the handedness of the artifact; three, let chance dictate whether the control interface would be left-hand or right-hand.

The horse-rider retained the influence of right-hand-preference to the present day so that the man/animal interface, equivalent to the man/machine interface, provides a stereotype control position, controls and method of using the controls from which there have been few deviations. Similarly, when man propells and steers a boat using a pole type artifact the majority use it to their right-side and hand. This example of the influence of human laterality was based on evidence from different parts of the world and from the operation of different types of craft and included the important example of the Venetian gondola and the Chinese river craft described by Worcester and referred to in 3.1.

The stereotype left-hand-on-the-reins, right-hand for whip or implement of the horsemman influenced the behaviour of the drivers of animal hauled vehicles. With the exception of the war chariots, the occasional driver who sat on the left and the important example of the
Conestoga waggoners, the right of medial position dominates the evidence.

Therefore the conclusion is reached that right-hand-preference has been the primary influence on the control behaviour of boatmen, horsemen, waggoners and coachmen and on the design of their vehicles and the equipment with which they exercise control.

The coachman practice, which became traditional, provided the early automobile control position designer with a stereotype which, in Britain, was retained down to the present day. The legislation, it is concluded, derived from a combination of whip-hand-preference, some religious/traditional factors and practical operating convenience as described in 3.2 and 3. This applied world-wide until the alternative drive-on-the-right rule, adopted for convenience of operation, was established for the greater part of the world.

It was not found possible to draw positive conclusions about the extent to which human laterality has influenced the establishment of the highway rules-of-the-road; as described in 3.2. The reinforcement of common practices by legislation was in itself of little consequence to the causality. Had legislation introduced rules which were contrary to common practice and those rules were significantly contrary to human lateral preferences, then legislative origins might have been of greater importance than common practices. In 3.2 reference is made to the decision of the Swedish government that the rule-of-the-road be changed from drive on the left to drive on the right and that the driver's position be on the track medial side of a vehicle. This is submitted as an example of a rule change which is not necessarily related to human lateral preferences.

The railway, particularly the steam-locomotive, initially exhibited handedness factors related, it is concluded, to the coachman-on-the-
right stereotype. This was an apparently straightforward conclusion to reach. However, the eventual stereotypes for the driver's position, adopted once railways had developed to a stable level of technology, were derived less from human laterality and more from operating convenience related to the bi-directional nature of the majority of railway routes. The driver's position was placed to the side which was closest to the trackside furniture; as described in 3.3. Had the steam locomotive remained the 'iron horse' with the driver able to see ahead and to both sides without his view being obscured by the body of the machine then the right-hand-drive locomotives might have been retained on 'keep-left' railway systems as a general rule rather than as an exception.

In the air man took with him some of the customs of the right-hand-world, particularly the Olympic direction of circling and the use of the primary control lever by the right-hand.

4.2.9
Freedom of designer's choice

One of the research objectives was to find in general terms the amount of freedom of choice open to designers when arranging the controls of a vehicle or craft. The horse, as a vehicle, had no characteristics of form or movement which might constrain the evolution of control equipment to one side in preference to the other. The lateral factors involved with the horse were derived from human lateral preferences.

Other land vehicles, hauled by draught animals—chariots, wagons and coaches—were essentially bilaterally symmetrical with asymmetry imposed on the design to enable 'skewed' man to exercise control using whip and reins.

Marine and river craft, in general, exhibited bilateral symmetry about the principal axis of movement and throughout their evolution, from primitive forms to the present day, designers were not constrained by mechanical or dynamic factors when arranging the control equipment; with
the possible exception of the preference for using a right-hand propeller screw action which imposed some bilateral asymmetry on the performance of a vessel but not on the way in which the controls were disposed relative to a vessel's medial.

The aircraft carrier was one example in which a mechanical and dynamic set of constraints, those derived from aviation, imposed an asymmetrical arrangement of the controls and control position.

Had the majority of Venetian gondoliers been left-hand and left-side-preferring then gondolas might have been made with hulls twisted in the opposite sense.

The steam locomotive, both primitive and modern, exhibited both examples of left and right-hand control positions and there were no significant mechanical and dynamic factors which might have influenced a designer to place the controls to one side in preference to the other. Human lateral preferences, traditional road vehicle practices and chance, in different combinations and degrees of influence resulted in approximately equal numbers of left- and right-hand drive locomotives.

The automobile, like the steam locomotive, evolved into both left and right hand driver versions each of which reflected a human preference to drive on a particular side of the road. Again, as with other types of vehicle, the automobile in an ideal symmetrical environment could exhibit both mechanical and dynamic characteristics none of which required any particular lateral offset of the controls. Only human lateral preferences, as in the first two decades of the automobile, influenced designers in the way they positioned the controls.

Of the five basic forms of transport studied for this thesis, the aircraft showed the most pronounced examples of the way in which mechanical, dynamic and human lateral factors had influenced the design of controls and the conduct of aircraft about the ways. This
influence was imposed despite the general bilateral symmetry of form adopted for the majority of aircraft. The aircraft operated in an environment which imposed no special set of rules of conduct. The three axis of control freedom were matched by symmetry of form. However, the imposition on the early aircraft types of mechanical factors such as torque, gyroscopic coupling and exhaust to one side, along with established turn preferences and human lateral factors, influenced significantly the subsequent way in which aircraft design and operation evolved.

4.2.10
The choice situation and the negative approach

When considering the possible reasons for a particular control arrangement in which the relevant factors had given the designer a free choice for positioning control equipment to the right or to the left of the control position or vehicle medial, it was considered important to allow for any possible influence from a negative or disinterested approach on the designer's part. Disinterest or the negative approach might be of greater significance than any questions of 'left or right'? As an example, during the design of a new vehicle a series of chance events might occur which result in a control position arrangement contrary to the available precepts of the ergonomists. Some of these events might be classed as 'indifference'. Other design events might be classed as the influence of hand and side preference. If the negative and indifferent attitudes to the series of design events predominate then the vehicle control position might include equipment which might be unacceptable when submitted to analysis. Perhaps it is a simplification to consider a series of 'indifferent' design events. What was more likely is the application of the generally accepted but little understood 'rule' of "put it on the right if in doubt".

Therefore, indifference has to be included in the possible items of influence when considering how a control system stereotype evolved.
In other words, traditional, 'instinctive' 'intuitive', ergonomics, human factors, industrial design and 'common sense' and mechanical limitations are not a sufficient number of factors to be considered when tracing the evolution of a specific control position and its equipment. Indifference or 'does it matter' may be the most significant factor.

4.2.11

The future

Having described the right-hand-world (RHW), specific vehicle and craft control artifacts and practices in relation to the right-hand-preferring (RHP) majority population so that the degree of the influence of human lateral preference characteristics is qualitatively described, these facts and inferences could be used to postulate the influence of human laterality on the design of future vehicles and craft.

In section 2 the diagrams of Fig 2.1 show the closed and open loops of the primary factors relating to man and his artifacts. These are approximately divided between the pre-RHW (c 5000BC) and the RHW of transport. A further division is that for the future and the diagrams are intended to show how ambidexterous artifacts are 'open-loop' as far as the present world is concerned but in the future they might reinforce the use of control arrangements, possibly control positions as well, in which there is little evidence of handedness or side preferences.

The example of natural selection by which evolution tends to proceed best from unspecialised types is, by analogy, applicable to artifacts. In other words, the future world of technology is likely to become increasingly less handed because man is now able to design man/machine less interfaces which are/influenced or constrained by human laterality. How far the future 'ambidexterous' world will, over hundreds of thousands of years, influence innate and learnt human laterality, so that man becomes completely bilaterally symmetrical, remains an unanswered question.
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Appendix A
Hand and Side-preference tests

Introduction

The objective of the hand and side-preference tests with subjects in the age range 8-11 years was to try and replicate the conceptual situation in which controls and instrument locations in a man/machine interface were selected in order to see if there were any influences from innate and learnt factors; particularly from their familiarity with dextrad forms such as handwriting and print (ref. 1.10).

The tests were intended to simulate decision situations which might have existed in the early days of man/machine interface development; such as factory, agricultural machinery and the application of steam power at the end of the 18th century.

It was realised that without being able to refer to evidence from research along similar lines the tests and results could be classified only as pilot-studies and were included as a suggestion for future research into the origins of man/machine interface decisions.

Age group for pilot-experiment in crane control positioning

The selection of the age group for the subjects in the pilot experiment on the positioning of the controls of a crane in a simulated man/machine interface was arrived at from consideration of the following factors:

a. The group's general lack of experience of controlling a crane
b. The group's general familiarity with the concept of levers as control inputs.

c. The group's ability to write.

d. In order to keep the pilot experiment as simple as possible and to match the availability of class groups in schools, the upper limit was set at 11 years.
The equipment and arrangement of experiment

Fig. 4A1 shows the arrangement of subject, furniture and the experiment equipment.

The furniture was that available in the school room used.

The matrix represented the control interface being simulated.

The three replica control levers and one instrument were made deliberately heavy and sturdy to enhance realism and to withstand constant handling.

The three levers were made to move in slots to impart a degree of realism in the simulated controls situation. The 'instrument' was a non-working replica.

The three levers were coloured and their functions and that of the 'instrument' were as follows:

Red for lifting the load up or lowering down
Blue for swinging the load from side to side
White for lowering or raising the crane jib

The instrument 'dial' to simulate an indication of the weight of the load and, with the levers, to enhance the simulation.

A box of sweets from which to gain covert indication of each subject's handedness

A photograph of a typical crane to reinforce the verbal briefing of the subjects.

The complete arrangement, as explained in the methodology was intended to simulate the controls of a typical moving jib crane similar to that shown in the photograph. Fig. 4A2.

It was realised that there were few standard layouts for controls of cranes. This was emphasised by White, T.G. (1973) 'Ergonomic Survey of Mobile Cranes'. jnl: App. Erg. 1973, 4, 2, 96-104, in which he comments on the variety of control layouts for mobile cranes.
General view of matrix and control equipment.
Typical Crane

Fig. 4A2
The subjects

With the enthusiastic help and encouragement of the Headmaster of the Bentinck Primary School, Nottingham, Mr. Alan Bowker and his staff, a group of 33 boys and girls in the age range 9-11 was made available as subjects. The majority of the subjects came from families with a background of unskilled and semi-skilled employment. Many came from immigrant families. In general the immigrant females were the most enthusiastic about the tests. The indigenous males the least enthusiastic. A random selection was not made of the available subjects.

Methodology

Each of the two groups of subjects were briefed as follows:

"We are trying to find out the best way of placing the controls of a crane. You can help by showing us where you think the controls should be placed in front of the crane driver". (ref. White 1973)

Each subject was tested individually and his or her actions concealed from the next subject who waited at the open door of the room. The object of allowing the waiting subject to hear but not see the progress of the experiment was to reinforce the verbal briefing each time and to enable the waiting subject to realise that the tests did not involve any daunting skill requirement. After checking name, age and noting any interest in drawing as a possible influence in addition to that of dextrad handwriting on spatial arrangements of items, the sex and indigenous or immigrant background of the subject were recorded.

Each subject was invited to take a sweet from a box which was placed immediately in front of them. The hand used for selection was noted along with other observations to determine the most likely hand-preference which was verified by questioning after the test. In addition to the group briefing on the overt objective of the test each subject was given an individual briefing to ensure that the methodology was understood and that they knew what a crane was and had a reasonable idea why it was
necessary to provide the driver of a crane with levers and instruments. The experimenter 'operated' the levers to demonstrate their simulated function but did not place them on the matrix.

The experimenter had to adjust the 'pattern' to suit each subject's individual attitude to the experiment and to encourage response without at the same time influencing the subject's choice of positions.

The 16 cell matrix, see Fig. 4A1, was placed in the middle of the table in front of the subject. The levers and the dial were placed in line on the extended medial of the subject and the matrix, as shown in Fig. 4A1. The four items were arranged in the order in which they had to be taken up and positioned by the subject: i.e. Red, Blue, White, Dial. The lever slots were along the line of the matrix medial.

Subjects were allowed to stand at the matrix but were instructed to keep to one position which was on the extended medial of the matrix. See Fig. 4A1.

The subject was asked to take the four items one at a time and place them in the cells of the matrix in an arrangement which indicated their preference when pretending that they were designing the controls of a crane shown in the photograph. Fig. 4A2.

The subject's actions and choice of positions were recorded by the experimenter who avoided any verbal or other forms of communication which might influence the subject.

When all the items had been placed on the matrix a second test was run using the same equipment and conditions in order to see if there was any similarity of results with those of the first test. Before the second test the subject was told that a second chance could be taken to see if the first pattern could be improved upon. The results of the second run for each subject were scored in the same way as for the first.
**Scoring**

The experimenter noted the positions chosen for each item in each test on a drawing of the matrix, see Fig. 4A3, which also shows the method of identifying items and data related to the subject. Fig. 4A3 includes a photograph of a typical pattern of control items.

With reference to Fig. 4A3:
The subject numbers refer to the pupils of the Bentinck Primary School, Nottingham.

Hand preference is that observed during an experiment.

Spatial ability: this is a crude measure obtained from questioning each subject about his or her ability and interest in drawing and was included as a possible guide to future experiments along these lines. The number to left of each matrix represents the factor of Symmetry and Order, 1, 2 or 3. (see section 'Symmetry and Order' for an explanation of the methodology).

The numbers on each matrix refer to the item numbers in order of placement. In the tests colours and letters were used to identify the control items so as to reduce the possibility of overtly influencing a subject to place the items in alphabetical or numerical order from left to right. The order of placement, Red, Blue, White, Dial (R.B.W.D) was considered a sufficiently random order.

A subject from an immigrant family is indicated by an asterisk against the sex. However, this factor was not used in the analysis of patterns but served only to indicate the degree of interest taken in the experiment compared with indigenous subjects.
Directionality of Pattern:

Subject No:

Sex: (an asterisk indicated an immigrant or subject from an immigrant family)

Hand preference: (from observation of the hand used to pick up a sweet and the hand used for placing the items on the matrix)

Age:

Spatial ability: (scored 0-10. This is an assessment of a subject's ability and interest in drawing obtained during the introductory phase of each experiment)

Fig. 4A3
Each matrix was analysed as follows:

**Directionality:**
This is indicated by an arrow and is based on analysis of the direction from Item 1 to Item 2. The comparison between the directionality of the first choice pattern (upper) and the second choice pattern (lower) provides a measure of similarity between the two patterns constructed by a subject.

**Symmetry and Order:**
For each pattern there is a factor to indicate symmetry about one item and order. This is used when analysing patterns to avoid as much as possible the influence of the experimenter's subjectivity. The method used for scoring the factor of symmetry and order is as follows:

The directionality of item 2 relative to item 1: if item 2 is on the same row as item 1, is in the same column or on one of the 45 degree diagonals from item 1 then this is scored ONE. If item 2 does not meet these conditions then the score is ZERO.

The relationship between item 3 and items 1 and 2: If this continues the linear relationship of 2 to 1 this is scored ONE. A score of ONE is also given if the position of item 3 completes a symmetrical grouping of three items.

The relationship of item 4 to the other items: if the position of item 4 completes a row, column or diagonal this is scored ONE; also if it completes a symmetrical grouping of the four items about itself which is on a vertical line, thus: \[ 1 \quad 2 \quad 4 \quad 3 \]; or completes a 'square' arrangement, thus: \[ 1 \quad 2 \]
\[ 4 \quad 3 \]
Using the analysis procedure described above each pattern was scored and allocated a factor of 0, 1, 2 or 3 depending on its characteristics. Those patterns with scores of 2 and 3 were classified as having symmetry and order compared with those with scores of 0 and 1.

Examples of typical patterns and the application of the analysis procedure are given in the following diagrams. Fig. 4A4 :-
Scored ZERO

Scored ONE
because of the relationship of item 2 to item 1 on same row.
Item 3 is not on a common row or column and item 4 does not make a symmetrical pattern.

Scored TWO
because item 1 and item 2 are on common row. Item 3 continues the pattern on the row but item 4 does not give a symmetrical pattern about itself.

Scored THREE
because item 2 is on a diagonal from item 1 and items 3 and 4 complete a symmetrical group.

Fig. 4A6
Scored ZERO

Scored ONE
because items 1 and 2 are on a diagonal but item 3 does not complete the line and item 4 does not provide symmetry

Scored TWO
because items 1 and 2 are on a diagonal with item 3 completing a symmetrical group. Item 4 is 'outside' the pattern

Scored THREE
because items 1 and 2 are on a row, 2 and 3 on a diagonal and 4 completes a symmetrical pattern

Fig. 4A4 continued.
Fig 4A5

The 66 resulting patterns of the Crane Controls Experiment at the Bentinck Primary School, Nottingham. Summer 1973
Directionality of first pattern (top) of second pattern (btm)
Subject No. ....... 1...
Sex. .... M...
Hand preference .... L...
Age .... 40...
Spatial ability (0-10) ... NA.

Directionality of first pattern (top) of second pattern (btm)
Subject No. ....... 2...
Sex. .... M...
Hand preference .... R...
Age .... 10...
Spatial ability (0-10) ... 5.

Directionality of first pattern (top) of second pattern (btm)
Subject No. ....... 3...
Sex. .... M...
Hand preference .... R...
Age .... 7...
Spatial ability (0-10) ... 3.

Directionality of first pattern (top) of second pattern (btm)
Subject No. ....... 4...
Sex. .... F...
Hand preference .... R...
Age .... 10...
Spatial ability (0-10) ... 5.
Directionality of first pattern (top) of second pattern (bottom)

Subject No. ...⑧...
Sex. ...M...
Hand preference ...L...
Age ...⑨...
Spatial ability (0-10) ...⑧...

Directionality of first pattern (top) of second pattern (bottom)

Subject No. ...⑩...
Sex. ...M.
Hand preference ...L.
Age ...⑩.
Spatial ability (0-10) ...⑧.

Directionality of first pattern (top) of second pattern (bottom)

Subject No. ...⑪...
Sex. ...F.
Hand preference ...R.
Age ...⑪.
Spatial ability (0-10) ...⑧.

Directionality of first pattern (top) of second pattern (bottom)

Subject No. ...⑫...
Sex. ...F.
Hand preference ...R.
Age ...⑪.
Spatial ability (0-10) ...⑧.
Directionality of first pattern (top) of second pattern (btm)
Subject No. 13
Sex. F
Hand preference R
Age 41
Spatial ability (0-10) 3

Directionality of first pattern (top) of second pattern (btm)
Subject No. 14
Sex. F
Hand preference R
Age 41
Spatial ability (0-10) 3

Directionality of first pattern (top) of second pattern (btm)
Subject No. 15
Sex. F
Hand preference R
Age 40
Spatial ability (0-10) 3

Directionality of first pattern (top) of second pattern (btm)
Subject No. 16
Sex. F
Hand preference R
Age 41
Spatial ability (0-10) 3
Directionality of first pattern (top) of second pattern (btm)
Subject No. 1234
Sex. M F
Hand preference
Age
Spatial ability (0-10)
<table>
<thead>
<tr>
<th></th>
<th>1</th>
<th>2</th>
<th>3</th>
</tr>
</thead>
<tbody>
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<td>0</td>
<td>4</td>
<td>2</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>2</td>
<td>4</td>
<td>1</td>
</tr>
<tr>
<td>2</td>
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<td>4</td>
<td>3</td>
</tr>
<tr>
<td>3</td>
<td>2</td>
<td>1</td>
<td>3</td>
</tr>
</tbody>
</table>

Directionality of first pattern (top)
Directionality of first pattern (top)
Directionality of first pattern (top)
Directionality of first pattern (top)

Subject No. .......30
Subject No. .......21
Subject No. .......22
Subject No. .......23

Sex. ...F...
Sex. ...F...
Sex. ...M...
Sex. ...M...

Hand preference ...R...
Hand preference ...L...
Hand preference ...R...
Hand preference ...R...

Age ..............11
Age ..............10
Age ..............11
Age ..............10

Spatial ability (0-10) 5
Spatial ability (0-10) 5
Spatial ability (0-10) 5
Spatial ability (0-10) 5

Right arm broken.
Directionality of first pattern (top) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm)

**Subject No.** 24  
**Sex.** M.  
**Hand preference.** R.  
**Age** 10  
**Spatial ability (0-10)** 2.  

Directionality of first pattern (top) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm)

**Subject No.** 25  
**Sex.** M.  
**Hand preference.** R.  
**Age** 11  
**Spatial ability (0-10)** ?  

Directionality of first pattern (top) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm)

**Subject No.** 26  
**Sex.** M.  
**Hand preference.** R.  
**Age** 11  
**Spatial ability (0-10)** 7.  

Directionality of first pattern (top) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm) of second pattern (btm)

**Subject No.** 27  
**Sex.** M.  
**Hand preference.** R.  
**Age** 11  
**Spatial ability (0-10)** 6.  

---

### Table 1: Subject Data

<table>
<thead>
<tr>
<th>Subject No</th>
<th>Sex</th>
<th>Hand Preference</th>
<th>Age</th>
<th>Spatial Ability (0-10)</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>M.</td>
<td>R.</td>
<td>10</td>
<td>2</td>
</tr>
<tr>
<td>25</td>
<td>M.</td>
<td>R.</td>
<td>11</td>
<td>?</td>
</tr>
<tr>
<td>26</td>
<td>M.</td>
<td>R.</td>
<td>11</td>
<td>7</td>
</tr>
<tr>
<td>27</td>
<td>M.</td>
<td>R.</td>
<td>11</td>
<td>6</td>
</tr>
</tbody>
</table>
Directionality of first pattern (top) of second pattern (btm)
Subject No. ....3...
Sex. ....M....
Hand preference ....R...
Age ....10...
Spatial ability (0-10) ...3...

Directionality of first pattern (top) of second pattern (btm)
Subject No. ....3...
Sex. ....M....
Hand preference ....R...
Age ....10...
Spatial ability (0-10) ...3...

Directionality of first pattern (top) of second pattern (btm)
Subject No. .......
Sex. .......
Hand preference .......
Age .......
Spatial ability (0-10) ...
Analysis of Patterns

Analysis of the positions selected for the first item (the red lever) representing the control used to lift the load up and down, were possibly of the most significance because the number of choices of position and the directionality to the second item and the general location of the group of four items were dependent on this first item position. Therefore the positions selected by the 33 subjects for this item were analysed as a separate factor.

Fig. 4A.a shows the distribution of preference between the columns of the matrix. The small difference between column 1 (left) and column 2 is not thought significant. The small difference between column 1 and column 4 might indicate that there was no influence from dextrad forms. However, if the results for columns 1 and 2 are combined then the ratio between those positions which might indicate the influence of dextrad forms and column 4, the contrary, becomes 42:17, about 2.2:1.
The positions selected for the first item (total of 66) were shown as a distribution by rows; as in Fig. 4A.b. If the dextrad handwriting and print forms had been an influence during the subjects' conceptual and decision-making behaviour then the uppermost row of the matrix might have been preferred. However, the results, as shown in Fig. 4A.b, do not substantiate this. The greater number of subjects tended towards selecting the middle level of the matrix. Rows 2 and 3 together give a total of 46 against 20 for the lowest and top rows, i.e. 46:20 about 2.3:1.

The top row of the matrix was the least favoured as the starting point for building the pattern of control items which, therefore, does not match a pattern which is strictly in accord with handwriting or print, set line by line from top to bottom of a space. A possible explanation could be from the common practice teachers have of starting written explanations on a blackboard at a position convenient to their reach which is rarely at the top left-hand corner of the board. At the same time there is the general observation of children writing or drawing, in which they rarely economise on space by starting at the top left corner; instead they tend to start a pattern away from the edges.
The 66 results for the position selected for item one (each subject made two patterns) are shown in Fig 4A.c. as a distribution by matrix cells.

Fig 4A.c. emphasises the analysis made by rows and columns but does appear to offer any significant data except the 'unpopularity' of cells 1/3, 2/3 and the uppermost row.

Statistical Analysis of First Item positions.

An analysis was made based on Chi-squared techniques using Pearson's Goodness of Fit Criterion and Tables from 'Statistical Methods of Research' by R.A. Fisher.

The following results were obtained:

1. Distribution by columns as in Fig 4A.a.
   Assuming an expected distribution by columns of 16, 5 and 3 degrees of freedom, then \( \chi^2 = 8.06 \) and \( \text{P} \approx 0.045 \) (\( \alpha = 0.05 \)).

2. Distribution by rows as in Fig 4A.b.
   Assuming an expected distribution by rows of 16, 5 and 3 degrees of freedom, then \( \chi^2 = 11.0 \) and \( \text{P} \approx 0.01 \) (\( \alpha = 0.05 \)).

3. Distribution by cells as in Fig 4A.c.
   Assuming an expected distribution of 4, 12 per cell (66/16) and 15 degrees of freedom, then \( \chi^2 = 21.38 \) and \( \text{P} \approx 0.13 \) (\( \alpha = 0.05 \)).

Therefore, the above \( \chi^2 \) tests indicate that the positions selected for the First item in 66 patterns were significantly different from the expected equal probability distribution when taken by rows and columns but when taken over 16 cells, as in 3 above, the positions selected for the First item were not significantly different.
Fig. 4A.d shows the distribution of directionality of item 2 relative to item 1.

The observation from this diagram which is of significance are the sizes of the ascending and descending diagonals, particularly that ascending, to the right of the origin (Item 1). This might indicate that those subjects had been influenced by the left-to-right directionality which forms a key concept in the works of Arnheim (1969), Gaffron (1950) and Klee (1961), which were referred to in 1.10. This relates to the preference for and the subjective effect of the diagonal which goes from bottom left to top right of a picture or spatial arrangement of discrete items. This aspect of directionality and its relationship with control interfaces is considered in 1.10 et seq.

Although the majority of subjects placed item 2 to the right of item 1, which might indicate the influence of dextrad forms, nevertheless the limitations of choice imposed by the size of the matrix (16 cells only) might invalidate such a conclusion.

The detail results from which the above observation was made were as follows: In 40 of the 66 patterns analysed, item 2 was placed to the right of item 1; in 24 patterns, item 2 was placed to the left of item 1, and in two patterns a vertical arrangement was used.

Fig. 4A.d. Distribution of Directionality of Item 2 relative to Item 1 from 66 results.
An analysis was made based on Chi-squared techniques using Pearson's Goodness of Fit Criterion and Tables from 'Statistical Methods of Research' by R.A. Fisher.

The following results were obtained.

Assumption One: That subjects had an equal choice of placing Item 2 to the Left or to the Right of Item 1. In 49 results the position of Item 1 gave the required freedom of choice because it was not in the extreme right-hand column.

Item 2 was placed to the right of Item 1 in 40 patterns out of 49.

Assumption Two: That an equal probability distribution was possible if subjects were uninfluenced by directionality factors, so that the distribution would be 24.5 to the left and 24.5 to the right of Item 1. \( (\alpha = 0.05) \)

For the above \( \chi^2 = 19.6 \), and with one degree of freedom \( P < 0.01 \).

Therefore the observed distribution of Item 2 relative to Item 1 is significantly different from the assumed equal probability distribution.

However, it was not concluded that the foregoing result indicated the influence of the dextrad form as an isolated factor because of the overall constraints placed on a subject's decision by the 16 cell matrix.

A further \( \chi^2 \) test of the observed results was made using the hypothesis that the dextrad form was an influence on the directionality of Item 2 relative to Item 1.

Assumptions:

a) The expected frequencies related to 49 sets in which there was freedom of choice between left and right of Item 1.

b) Of the 49 sets the expected frequencies were related to the general observation of dextrad linear forms which favoured L to R ascending diagonal and the L to R horizontal arrangements and less favoured the descending L to R diagonal.

Therefore directions B, C and D in Fig 4A.d were given expected frequencies of 20, 20 and 9 respectively. The remaining sets (66-49) were given expected frequencies of \( (66-49)/5 = 3.4 \).

c) The degrees of freedom = 8-1. \( (\alpha = 0.05) \)

For the above \( \chi^2 \approx 219 \) and \( P < 0.001 \). Therefore the hypothesis was not substantiated.
Similarity between the first and second choice of directionality between items 2 and 1 and general form of the pattern was apparent with 16 of the 33 subjects. However, it was recognised that this might only be an indication of those subjects who were content with their first arrangement and those who were motivated to improve on their first choice or wanted to experiment.

Fig. 4A.e and the detailed analysis of the 66 patterns was used to give an indication of the skewedness of patterns.

Fig. 4A.e shows the distribution of 264 (66 x 4) positions selected. The distribution is shown by rows and about the vertical medial.

![Distribution of 264 Control Positions on the four rows of the Matrix and about the Vertical Medial](image)

In 12 of the 66 patterns all four items were skewed to the left of the medial. 22 were skewed to the right and 28 were arranged symmetrically about the vertical medial.

Had the pattern direction not been limited by the size of the matrix then the result, in which nearly twice as many patterns were to the right compared with to the left, might indicate the influence of the dextrad form.
Factor of Symmetry and Order

Using the methodology described in Fig. 4A4, each of the 66 patterns was allocated a number to indicate the degree of symmetry and order represented by the relationship between the four items.

The distribution of the 66 patterns against the four classifications is shown in Fig. 4A.g.

It was hypothesised that some subjects might be influenced primarily by symmetry and order and therefore this was a factor to be considered when analysing all the patterns of the experiment. The influence of symmetry and order as a motivation might be stronger than that of the dextrad forms.

Of the 66 patterns, 28 were classified as exhibiting symmetry and order. Of those 28 patterns, 13 were not classified as exhibiting left-to-right directionality. 15 were dextrad in form. A result considered to be inconclusive because of the small number of examples.

Therefore, within the limitations of this pilot experiment, conclusions about the relationship between symmetry and order and the influence of the dextrad form were not justifiable. In full scale testing this might be an important factor for consideration.
Summary of results and conclusions from the analysis of 66 patterns.

Position of first item of a pattern.

Overall, the positions selected for the first item in the group of four simulated controls were the most important because they were most likely to represent the result of a spontaneous approach to the task in which innate and learnt factors had been the primary causes of a subject's behaviour when conceptualising and constructing a control arrangement. Once the position for the first item had been selected the number of directions available for building up linear arrangements was limited by the size of the matrix. Intentionally the 16 cell matrix was selected because it had no axis of symmetry made up of cells and therefore it might limit the influence of simple pattern symmetry as a goal.

Also the use of a 16 cell matrix had the advantage of limiting the choice of patterns thereby keeping the experiment as simple as possible, and of making the task appear less daunting.

A subject's choice of position for the first of the four items influenced the subsequent selections because items 2, 3 and 4 tended to be placed in the directions which offered the greater freedom of choice. Therefore, the principal value of the tests came from first observing to which side of the vertical medial subjects placed the first item, followed by an analysis of directionality, 'symmetry and order' and the relationship to the expected pattern of control items based on the dextrad form.

The results showed that nearly twice as many of the subjects placed the first item to the left of the vertical medial. This result was confirmed during the second test with each subject. In full scale testing this result might indicate that the dextrad forms were a primary influence.
Symmetry and order of pattern

As noted, a factor of symmetry and order was allocated to each of the 66 patterns and the relationship with left-to-right directionality was determined but, within the limitations of the experiment, conclusions about any significance were not justified.

Opposing factors

Another factor considered when analysing the positions chosen for the first item relates to the conceptual and motor actions used to place Item 1 in a cell by reaching forward, lifting it up and putting it down. It is inferred that the total process involves a number of conflicting actions two of which might be: (a) the shortest path between store and cell; and (b) possible influence of the dextrad forms. When the preferred hand of a subject was the right-hand it was inferred that this might induce a subject to choose cells towards the right-hand side of the matrix and this might oppose any influence from a subject's experience of dextrad forms which might favour selection of cells to the left of the vertical medial for the position of item 1. Tests with a sufficiently large number of subjects might verify this relationship between these two possible and conflicting influences. As noted, the majority placed the first item to the left of the medial. Overall it was observed that subjects were not constrained by the form of the experiment and that few made a direct store to matrix move.

Once the first item had been positioned a new set of handedness factors applied and the arm and the hand on the same side as that conceived for the position of the next item was sometimes used, irrespective of the subject's observed hand-preference.
'Expected' pattern

Consideration was given to the possible matching of some of the patterns with an 'expected' pattern which was based on the dextrad form. The 'expected' pattern which was selected for comparison was the left-to-right order 1,2,3,4, with item 4 on the same line or above or below the other three items, thus: 1,2,3,4 or 1,2,3 or 1,2,3 4

Of the 66 patterns analysed none matched the 'expected' dextrad form. Only subject No.25, see Fig. 4A5/7, came close to the 'expected' form.

Stereotype pattern

Consideration was given to using an 'expected' pattern based on stereotype control arrangements in which the preferred hand of the majority would operate the hoist control (item 1), the non-preferred hand operates the left-right slew lever and the third lever is in the middle with the instrument dial above it; thus: 2,3,1. However, this arrangement was not used because the subjects were not expected to appreciate the best ergonomics for a set of crane controls.

Direction of simulated lever movement.
The three lever units were positioned at the start of each test with the lever slots in line along the medial of the matrix and of the subject. The experimental observations did not include the relationship of the lever slot to the simulated function of a lever. For example, the lever for slewing the crane was not necessarily positioned in a cell in accordance with accepted direction-of-motion stereotypes. The majority of subjects maintained the initial orientation of a lever unit when placing it in a cell.
Space vehicle controls experiment

The pilot study described in section 4 Appendix A produced
recommendations for future research based on full scale, large
population of subjects tests along the same lines. Verification
of the results of testing 9-11 year old subjects might come from
tests with adults.

The control test might use a 49 cell matrix and replica push­
button control modules to simulate the control interface of a space
vehicle capable of the following freedoms of control:-

(a) Fore and aft
(b) Faster or slower vectoring
(c) Up or down
(d) Left and right

In order to verify the suitability of the proposed control test
the following categories of people were asked to select the positioning
of the controls of a hypothetical space craft using a 16 cell matrix:

1. An experienced and enthusiastic motorist with a knowledge
   of instrument and controls design. RHP.
2. An experienced pilot with a knowledge of instrument and
   controls design. RHP.
3. A statistical analyst with a driver's licence. RHP.
4. A print and artwork designer in control and instrumentation
   publicity. RHP.
5. An aeronautical engineer. RHP.
6. A female motorist. LHP.
Preliminary experiment

The subjects, as listed supra, were asked to place 4 control modules in a matrix of 16 cells so as to simulate the design of the control interface of a space craft.

The 16 cell matrix was placed in front of the subject and the four control modules placed in line on the extended medial of the subject and the matrix and in the order in which they were to be placed on the matrix. See Fig. 4B.1.

The object of the experiment, which was not conveyed to the subjects, was to obtain results from which it might be possible to determine the directionality of a population's behaviour when conceptualising a control interface.

Recording was done on a diagram of the matrix in a way similar to that described in Appendix A. See Fig. 4B.2.

The results were not analysed because of the few experiments made and because the analysis of the results of the tests described in Appendix A had shown clearly the limitations of using a 16 cell matrix for tests intended to indicate lateral and directional preferences.

As with the tests in Appendix A of school children, a 49 cell matrix is recommended for full scale testing in the future.
Forward/Aft ............ Item 4
Up/Down ............ " 3
Left/Right ............ " 2
Speed +/--- ............ " 1

Matrix

Medial of subject

Layout of equipment

subject

subject's medial

Fig. 4B.1
<table>
<thead>
<tr>
<th>Subject</th>
<th>Hand Preference</th>
<th>1st Test</th>
<th>2nd Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>No.1</td>
<td>RHP</td>
<td><img src="image1" alt="Grid" /></td>
<td><img src="image2" alt="Grid" /></td>
</tr>
<tr>
<td>No.2</td>
<td>RHP</td>
<td><img src="image3" alt="Grid" /></td>
<td><img src="image4" alt="Grid" /></td>
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<tr>
<td>No.3</td>
<td>RHP</td>
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<td><img src="image6" alt="Grid" /></td>
</tr>
<tr>
<td>No.4</td>
<td>RHP</td>
<td><img src="image7" alt="Grid" /></td>
<td><img src="image8" alt="Grid" /></td>
</tr>
<tr>
<td>No.5</td>
<td>RHP</td>
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<td><img src="image10" alt="Grid" /></td>
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<tr>
<td>No.6</td>
<td>LHP</td>
<td><img src="image11" alt="Grid" /></td>
<td><img src="image12" alt="Grid" /></td>
</tr>
</tbody>
</table>

Examples of results in Space Vehicle Controls Experiment

Fig. 4B.2