# HUMAN CONTROL OF SHIPS IN TRACKING TASKS

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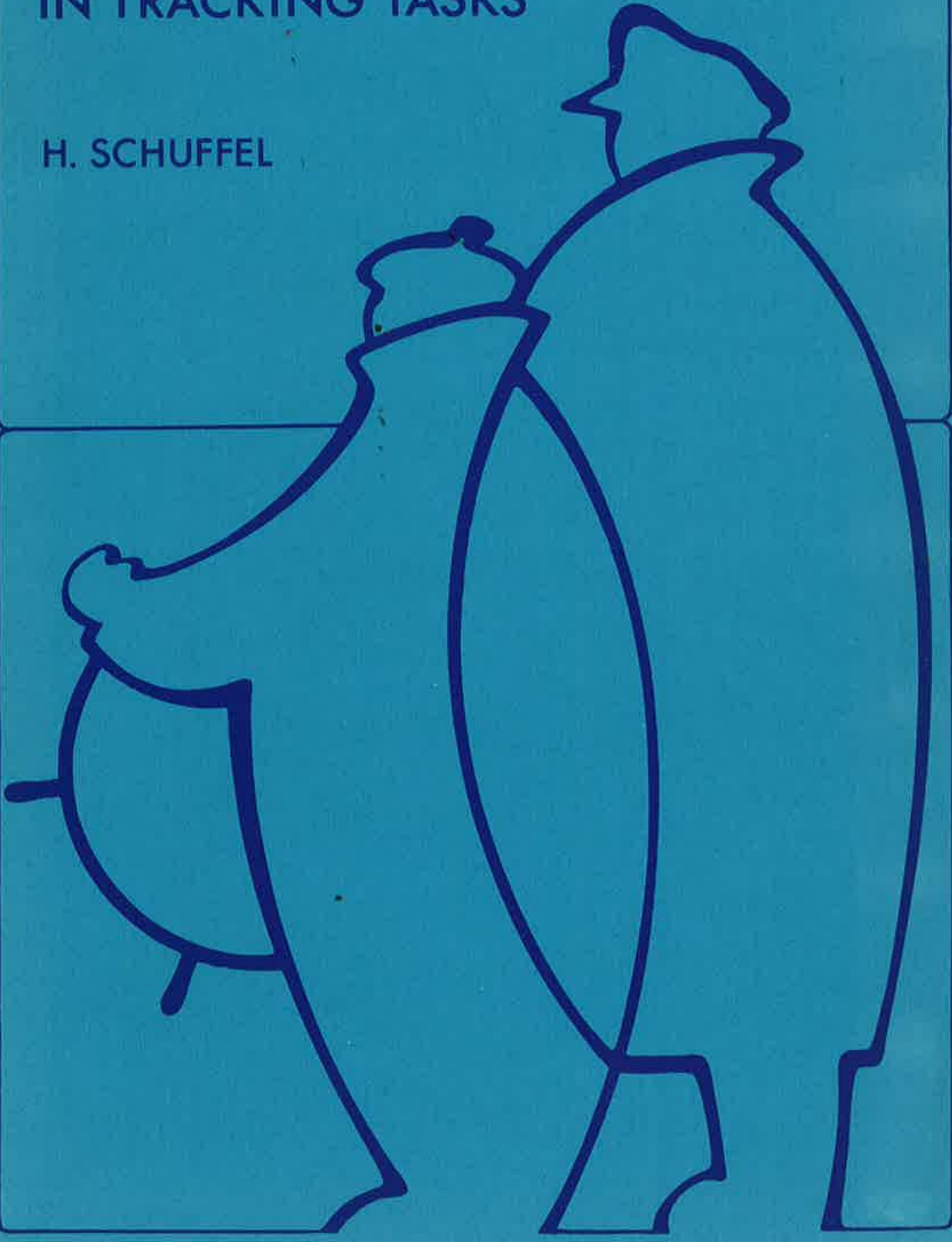

# HUMAN CONTROL OF SHIPS
# IN TRACKING TASKS

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Aan Nel,
Herke en Jaconelle
Aan mijn schoonmoeder

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CONTENTS

# 1 INTRODUCTION

## 1.1 Scope

Research on the control of ships has traditionally been concerned with engineering aspects of path keeping, path changing and speed changing characteristics of vessels. Research on human control of ships became of interest as the conviction grew that the human element is a severely limiting factor (Wagenaar, 1970). This interest led to the consideration of man and ship as related rather than as separate elements. In one study (SNAME, 1975), the integrated human/ship performance was described as **piloted controllability**, defined as the relative ability of a piloted vessel to change position and orientation at desired rates. A piloted vessel is considered as one which is under the direct control of a skilled ship handler.

Indeed, the ship handler's skill seems to be a most critical factor with regard to the safety of the ship, in particular when accurate control of position and orientation is needed. About 75% of shipping accidents happen during coastal and terminal navigation (ICS, 1975) and they are primarily due to human error (Margetts, 1976). For instance, the causal factors of strandings are usually wrong estimates of the ship's movement and position, probably caused by a combination of external factors, such as restricted visibility, the vessel's drift and limited manoeuvring space (Kristiansen, 1980).

Besides the effects on the ship's safety of the ship handler's skill and the ship surroundings, the ship's bridge layout seems also to be a critical factor. A ship's bridge is supposed to function as an interface between the ship handler, the ship and its environment; hence the question arises as to what extent bridge design can support the ship handler's sensory, information processing and motor handling activities. On the basis of accident analyses and questionnaires, Margetts (1976) has listed 14 factors which are major or potential causes of accidents at sea. The study suggests human variables such as inattention and ambigious pilot-master relationships, but also sub-optimal bridge design as important causal factors. These findings parallel those of Drager et al. (1981) who also analysed the causal relationships of shipping accidents.

Moreover, the search for cost-effective operation of ships emphasizes trends towards increasing automation and manpower reduction (KNRV, 1981; Doi, 1981; Maydell, 1981). With regard to ship control tasks and in particular to navigational tasks performed on the ship's bridge, the operators will perform more supervisory and fewer manual control tasks. As in many comparable industrial supervisory tasks, the question emerges, as to whether a ship handler is capable of understanding an automaton's performance and consequently whether he can reliably function as a supervisor.

Generally, little is known about the ship handler's skill for navigating in confined waters (Gardenier, 1981). Attempts to gain knowledge on this matter by top-down approaches have been made (e.g. Drager et al., 1981; Kristiansen, 1980; Mara, 1968), but the resulting observational data have only led to expectations and not to research involved with predictions and checks of the ship handler's functioning. Theoretical studies with a bottom-up approach (e.g. Veldhuyzen, 1976) are few in number and parallel studies in the field of process controllers of slow responding systems (Edwards and Lees, 1974). These studies are commonly based on the generally accepted notion of an operator's internal model, representing his knowledge of the process dynamics under control (Wickens, 1983). This may be used to explain anticipatory actions of the operator when compensating for control errors arising from the delay of process responses. Yet, the internal model notion does not cover specifically control behaviour in terminal navigation. Moreover, the navigational task is far too complex to be amenable to theoretical research. Hence, the state of the art pleads for a balancing of empirical and theoretical aspects of the ship handler's control behaviour by analysing simplified navigational tasks as well as by exploring theoretical approaches.

In conclusion, the ship handler's skill, to a certain extent affected by bridge design, is of considerable importance with regard to the safety of ship control in conditions of restricted manoeuvring space. Since the current understanding of such behaviour is incomplete and specific theories on such skills are lacking, the aim of this study is to examine some components of the ship handler's performance.

## 1.2 General Method

Attempts to measure the ship handler's control activities vary from real life and field studies to simulator and laboratory experiments.

Various earlier studies have provided information on the ship handler's control activities. Mara (1968) and Moe et al. (1974) analysed bridge officers' control activities. Lewis (1969) conducted field experiments on human control of ships. Moraal et al. (1973) and Ivergård (1976) gathered mariners' opinions on control performance by means of questionnaires, and Huffner (1976) attempted to analyse the control behaviour of ship pilots by means of verbal protocols. These approaches have a serious common drawback in that they fail to consider a large number of variable factors which affect control behaviour.

In the present study results from **simulator** experiments approximating real life conditions are combined with **laboratory** experiments. Their combination may facilitate the generalization and interpretation of results (Sanders, 1983). The simulator experiments are conducted with the simulator as described in the appendix and concern the control of a 40,000 ton container vessel. This type of vessel represents a class of easy manoeuvrable modern freighters. The experiments are aimed at testing expectations inferred from accident analyses (e.g. Drager et al., 1981; Margetts, 1976) and allow for generalization of results (Schuffel et al., 1978). Because of the complexity of such simulator experiments, hypotheses on performance need to be tested in simplified conditions to provide sufficient means for falsification.

Simulator experiments are usually rather complex. The implicit background is that because of the complexity of the ship control task, the simulated task should be at least as complex in order to be realistic. It is hoped that the realism obtained renders the generalization from simulator to sea or inland navigation conditions acceptable. Yet from an experimental viewpoint, this approach leads to a lack of control of a number of variables which, in turn, puts at least some constraints on the interpretation of the results. Sanders (1976) has pointed out some differences between laboratory experiments and very elaborate simulator studies. The laboratory experiment enables conclusions about the effects of system elements, but generalization of the laboratory results to the actual situation is more dubious. In contrast, simulator experiments may deliver results that are applicable but do not clearly reveal causal relationships between system elements and system performance. Gopher and Sanders (1984) suggest combining laboratory experiments within a strict axiomatic theoretical framework with less axiomatically constrained simulator experiments. Converging evidence from these two approaches should bridge the gap between the more abstract laboratory experiment and the realism of the simulation.

This notion of carrying out pairs of related experiments seems to be highly relevant for studying the ship handler's control behaviour. On the one hand there is the need of testing hypotheses on control behaviour within a constrained framework, on the other hand there is a gap between the generalization of experimental results and the interpretation of navigational performance.

When, in a context of paired experiments, simulator experiments represent "real-life conditions", the problem of coping with complexity remains. Jones (1978) for instance, has shown that scenarios employed to analyse anti-collision navigation, do not offer constant task demands in time and space. In the case of multi-ship scenarios, it is rarely possible to make any meaningful forecast as to how the scenarios will develop after the first action has been taken. To avoid those problems in the present study, the ship control task is limited to the tracking of planned routes in terminal navigation, excluding other ship traffic.

Summarizing the method, it is proposed combining two types of experiments. Simulator experiments are aimed at bridging the gap between laboratory experiments and practice. The complex navigational task is limited to the tracking of planned routes. Corresponding laboratory experiments are aimed at testing hypotheses of ship handler's performance. They are focussed on the prediction and checking of isolated control actions in a more strict theoretical framework.

## 1.3 Ship control as a tracking task

Controlling a ship can be considered as a goal-oriented control process with a hierarchy of tasks (Kelley, 1968). In the organization of sea passages, passage planning is distinguished from the actual conduct of the passage (DT, 1980; Spaans and Goldsteen, 1983).

With regard to planning, there is partially reliable information about the potential routes and about meteorological and ship conditions in order to decide about the route to be followed. On the actual conduct, the deviation between planned and actual route or position is monitored. The planned route or position can be foreseen by observing the ship's surroundings and also by using information from charts or almanacs or by consulting human pilots. The vessel's response as a function of rudder deflection, propellor revolutions and exterior forces can be predicted by the ship handler's knowledge of the ship's dynamics and can be inferred from the ship's movements. The monitoring span for such predictions may range from minutes to hours. Decisions may consist of orders about heading and speed or of adjustments of the set-points of automated control loops. The response activities, such as rudder control for minimizing a deviation between the planned route and the actual (expected) position are, next to the monitoring, a second element of the actual conduct. The control span ranges from seconds to minutes. Control actions have the aim of reducing errors.

Planning, monitoring and response activities all bear upon four basic mental functions, i.e., information encoding, information processing, information storing and motor control. All these functions may be allocated either to one ship handler, to a number of bridge personnel or to personnel and automatons (Boer and Schuffel, 1985). Automatons and instruments are meant to extend the ship handler's ability to cope with tasks under various conditions. It is obvious that the ability to deal with a variety of tasks at the same time in a flexible way constitutes the most important reason for using human beings in such control tasks.

The piloted controllability as mentioned in paragraph 1.1, refers to the control of the ship's position and heading to arrive at a desired time, taking into account safety and speed criteria.

Performance with regard to safety and speed criteria is determined by the navigational area and the pacing of the control task. Thus, when conducting a vessel from an initial to a desired position within a certain period of time, the probability of groundings and collisions when taking the shortest route at the highest speed has to be weighed against other combinations of route-length and speed. It is therefore useful to distinguish three types of navigational area (Spaans, 1981). On the open sea, the vessel can be properly navigated when the latitude and longitude of the ship's position are known, as well as its true heading and speed. On the open sea, extreme weather conditions excepted, the ship may be considered as a mass-point. This implies that with few or no obstructions on the vessel's planned track the maximal (or economical) speed can be adjusted. Coastal and terminal navigation, however, require consideration of surroundings. Accurate positioning is needed, taking into account the vessel's dimensions as well as its position and movements. Thus in narrow fairways, safety is primarily related to the accurate knowledge and control of the ship's position and heading. The ship handler has to weigh speed and safety of performance in order to assess the risks of failing to meet performance standards. It is known from interviews (Margetts, 1976) that mariners accept taking risks in particular for economical reasons (Janssen, 1979).

To cope with these complexities, it is proposed in section 1.2 to reduce the ship control task to the tracking of planned routes. Hence, the planning and the safety versus speed weighing processes are excluded. Investigations are concentrated on the ability of the ship handler to follow a given intended route. The tracking of planned routes (the ship tracking task) can be considered as a laboratory tracking task, which is specified as follows by Adams (1971):

* A paced externally-programmed input or command signal defines a motor response for the operator, which he performs by manipulating a control mechanism.

* The control mechanism generates an output signal.

* The input signal minus the output signal is the tracking error quantity and the operator's requirement is to null this error. The mode of presenting the error depends upon the particular configurations of the tracking task, but, whatever the mode, the fundamental requirement of error nulling always prevails.

* The measure of operator proficiency ordinarily is some function of time-based error quantity (Adams, 1971, p. 169).

The elements involved in tracking an externally-programmed input with a ship are best appreciated by considering the man/ship system as shown in Fig. 1.1, which refers to the previously mentioned concept of piloted controllability. Starting at the left in an ideal case, the actual ship's position and orientation can be seen through the windows of the wheelhouse and on instruments. The track which the ship handler wants the ship to follow is inferred from the ship handler's memory and from the passage planning, visible on a chart or on a display. If the track and the travelled path do not coincide or are about to deviate, the handler can take anticipatory corrective actions by changing the heading in a direction that will tend to correct the path error. The heading change can be executed by the ship handler or by an autopilot. External disturbances such as wind, waves and current are also simultaneously acting on the ship and since not all necessary information is always optimally available to the ship handler system performance will tend to be sub-optimal.

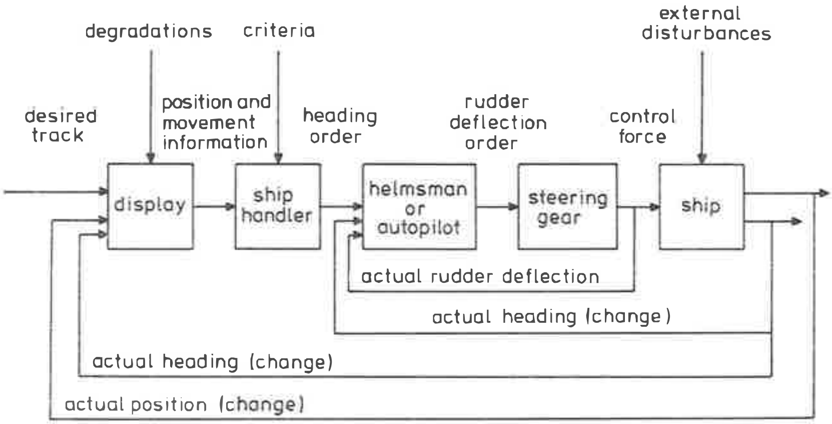


Fig. 1.1 The ship tracking task as a function of the ship handler's ability, the vessel dynamics and its disturbances, the task, the means for control, and the presentation of ship parameters and ship surroundings.

Common elements of a **laboratory** tracking task and the tracking of planned routes in real-life conditions are the prediction of inputs (e.g. Poulton, 1957), the prediction of outputs (e.g. Kelley,

1968) and the anticipation of future deviations between inputs and outputs (e.g. Kelley, 1968; Sheridan, 1966). As will be further detailed in Chapter 2, the tracking task paradigm offers the opportunity to discuss the literature on these matters with regard to the ship handler's performance.

In order to clearly define the ship handler's ability to change the ship's position and orientation at desired rates, a number of variables in the **laboratory** tracking task have to be properly controlled with regard to the tracking of planned routes in real life (ship tracking task). The relevant aspects are briefly mentioned here.

(1) The **pacing** of the ship tracking task is based upon a complex relationship between the shipping company's orders and the mariner's interpretations of the need to meet performance criteria. Research into the ship handler's abilities will be limited here to predetermined speeds, excluding subjective weighing of performance criteria.

(2) When the ship tracking task is viewed as the **accurate pursuit** of a desired track at a predetermined speed, the system tracking error quantity reflects, as in the laboratory tracking task, the operator's tracking proficiency.

(3) The ship's **surroundings** will normally determine the track. As the geometry of the surroundings might affect the handler's performance in specific ways, these effects have to be either minimized in a laboratory tracking task or explicitly stated.

(4) The ship's **manoeuvring characteristics** will also affect the ship handler's performance. The ship handler's ability, therefore, has to be defined relative to given characteristics of the ship.

(5) The ship tracking task contains compensatory as well as pursuit tracking elements. The interest of this study is focussed on the control behaviour while **pursuing an intended track.** Hence tracking behaviour when compensating for disturbances is not considered.

(6) Most often, more than one person is involved in the ship tracking task. In the present study only **one person** is considered, which means that interactions between mate and helmsman (or automatons) are ignored.

(7) Kinetic feedback, both due to the ship's movements and to forces acting on controls are also not considered.

## 1.4 Preview

Summarizing the argument so far, hypotheses on the ship handler's control performance are formulated and tested with regard to monitoring and controlling a ship's progress in tracking planned routes. Because of the large number of variables involved, the ship tracking task will be reduced to a **laboratory tracking task.** A desired track - i.e. an externally programmed forcing function, defines a motor response for the operator which he performs by manipulating the ship's rudder. The ship's path travelled minus the desired track is the tracking error quantity and the operator's requirement is to null this error. Within this scope the organization of this thesis is as follows:

The most relevant literature about the organization of control behaviour, performance in tracking tasks, manual control of slow responding systems and the theory of motor-skill learning is discussed in **Chapter 2.** A theory of control behaviour is proposed that contains two complementary elements: response selection (control setting) is assumed to be either **stimulus-related** (preprogrammed control) or **effect-related** (feedback control). Notions on preprogrammed control behaviour primarily depend on stimulus related control responses (motor memory), while notions on feedback control principles primarily depend on effect-related control settings and the development of references for evaluating the correctness of system performance (perceptual memory).

Hypotheses are tested by means of two types of experiments: simulator experiments providing conclusions about the system performance, and laboratory experiments within a strict theoretical framework providing conclusions about the ship handler's performance.

In **Chapter 3** the results of simulator experiments about the tracking ability of pilots and students are discussed. The layout of the tracks aims at obtaining general conclusions about ship control. It offers the ship handler varying degrees of freedom with regard to response corrections so as to enable the testing of the limits of control behaviour. A track without any opportunity for corrections represents the ultimate control limit and requires the preprogramming of responses (open loop), while tracks with ample opportunity for corrections also permit feedback-related responses. The tracks are related to the manoeuvring characteristics of the vessel under control: a 40,000 ton container vessel at an initial forward speed of 20 knots (see Appendix).

The tracking performance of both pilots and students is studied with regard to the question as to what extent experienced mariners and novices base their behaviour on either a motor or a perceptual memory. The results show moderate tracking errors for both groups of subjects and fairly similar performance levels after training in the present set of simplified conditions. It is suggested that both groups develop a perceptual memory which seems to be the most relevant behavioural component with regard to accurate tracking performance. Performance levels are related to real-life conditions by comparing rudder deflection deviations in the simulator with those in trials at sea.

In combination with results of an experiment on performance of experienced pilots, a feedback control hypothesis is supported. A preprogrammed control hypothesis is not confirmed. The framework of the simulator experiments, however, is too wide to allow a more detailed theoretical analysis.

In Chapter 4, 5 and 6 further experiments about preprogrammed and feedback control are presented and discussed.

**Chapter 4** considers the hypothesis of response preprogramming in approaching a desired position. The results show rather inaccurate response selection. The hypothesis that elaborate programmes underlie accurate control actions is not confirmed. The accuracy of response selection is further scrutinized in this chapter by examining the effects of knowledge of results about performance. It appears that knowledge of results improves the accuracy of the response when the correct response after control setting is provided. These results fail to support a preprogrammed control hypothesis, which assumes that information about the response outcome creates a more accurate response in a next trial.

In **Chapter** 5 the hypothesis concerning preprogrammed control is tested with regard to response selection in conditions where - within certain time limits - subjects are asked to reduce a ship's initial turning rate. The results show inaccurate performance, which argues again against a dominant role of preprogrammed control.

In **Chapter** 6 the feedback control hypothesis is further tested. Results of tracking experiments show accurate results when the desired track is either visible or when subjects are explicitly instructed to use certain aiming points for evaluating performance accuracy. Large tracking errors - although decreasing as a function of training - are observed when subjects are merely instructed to eliminate deviations between the desired track and the travelled path. These findings support the feedback control hypothesis with emphasis on the development of a perceptual memory.

The thesis is concluded with an epilogue (**Chapter 7**) in which the main conclusions of this study are summarized. It is concluded that the ship handler's performance is primarily based on feedback control and that the accuracy of tracking performance depends on the development or availability of a perceptual memory. Preprogrammed control (open-loop control) is rather inaccurate and it is unlikely that this is acquired in real-life. The question of whether the preprogramming of responses and the development of performance references are unique for specific task conditions or can be inferred by interpolation from already stored experiences was not explicitly addressed but is an issue of considerable interest and is suggested for further research.

# 2 SHIP HANDLER'S CONTROL BEHAVIOUR

## 2.1 Organization of human control behaviour

Human control of vehicles can be conceived of as goal-oriented behaviour, performed at several hierarchically organized levels. This viewpoint is the essence of Kelley's (1968) theory on manual control. Other authors (e.g. Crossman and Cooke, 1962; Krendel and McRuer, 1968; Pew, 1974; Rasmussen, 1976; Broadbent, 1977; Johannsen and Rouse, 1978) have formulated similar notions but with more emphasis on different aspects of human control behaviour. Broadbent (1977) for instance has proposed that control behaviour at some lower level can function independently, being only monitored and supervised by a higher level. This notion implies that, except when mutually exclusive on peripheral grounds, various automatic activities can be performed simultaneously and need little attention from a higher level whereas relatively new activities need continuous attention, so that parallel performance is impossible (see also Shiffrin and Schneider, 1977; Navon and Gopher, 1979; Pew, 1984).

Regarding the acquisition of motor skills, Fitts (1964) and Fitts and Posner (1967) have distinguished a cognitive, an associative and an autonomous phase of motor learning. In the first phase performance is usually inconsistent, presumably because the operator is testing hypotheses on control activities. Generally, performance improves considerably in this phase. In the associative phase the most effective ways of controlling are further elaborated and performance improves gradually. Performance in the third phase is characterized by a considerable reduction in attentional demands required for the performance of tasks.

Given these phases of motor learning, at least two levels of control can be distinguished:

1 **Planning level** The conception and selection of goals by deciding about possible future states of the controlled variable and by choosing the desired states with regard to performance criteria. To realize the chosen future states, procedures are developed for proper control actions at lower levels and lower level performance is supervised.

2 **Execution level** Control actions are carried out with the aim of correcting (expected) deviations between the desired and actual (expected future) state of the controlled variable. When overlearned, actions can be executed automatically, but its actions are still monitored by the planning level (see also Sanders, 1983; Pew, 1984).

Some authors suggest an intermediate level between planning and execution which would deal with recognition and recall of procedures for instructing the execution level (Rasmussen, 1976). In the present study a possible intermediate level is not considered, because it does not seem to be strictly necessary for interpreting control behaviour. This view is in line with Broadbent (1977) and Neumann (1983). When recognition and recall occur automatically they appear to belong to a longer chain of automatic activities. Therefore, there is no reason to consider them separately.

Planning and execution can also be distinguished with regard to the ship handler's levels of control during tracking. At the planning level possible paths are conceptualized and selected which are as close as possible to the planned (desired) track. According to Kelley (1968), the ship handler weighs the performance criteria and evaluates which path will occur if no or further control actions are taken. This evaluation has the context of a set of programmes (procedures) for adequate control actions. At the execution level heading (rudder) and speed (shaft revolutions) control actions are specified and executed. They are monitored at the planning level.

Since not much is known about ship handler skills (Gardenier, 1981), the question remains to what extent control actions may occur automatically. It could be that automatic control is limited to frequent, small corrective inputs, and that behaviour remains in the cognitive and the associative phase of motor learning for the planned actions of major ship state changes because of the ever changing environmental conditions which disturb the development of preprogramming and of stabilizing a set of performance references.

The slow response of vessels to control actions, encourages the ship handler to plan the ship's future position in order to avoid errors due to response lag. The ship handler's ability to anticipate seems to be therefore the most essential skill when manoeuvring in narrow fairways. In the next section the ability of anticipation will be further discussed.

## 2.2 Anticipating the desired track and the ship's path

In a tracking task operators can anticipate future errors when at time t the state of the output variable and of the input variable can be predicted with reasonable certainty for time $t + \Delta t$. Hence, anticipation results in minimal deviations in time and space between the state of both variables which might otherwise occur due to response lag.

For tracking tasks, control actions based on prediction of the future state of the system input variables can be distinguished from the control actions based on prediction of the future state of the system output variables. Anticipation of input variables have been extensively investigated by Poulton (1952; 1957b). Anticipation of output variables has been investigated mainly in the context of controlling slow responding systems (e.g. Kelley, 1968; Edwards, 1974). Both forms of anticipatory behaviour are briefly discussed below.

### 2.2.1 The desired track

Anticipating the desired track in a ship tracking task can be compared with anticipating the stimulus course in a laboratory tracking task. Poulton (1952; 1957b) has distinguished three types of stimulus anticipation:

* **Receptor anticipation.** When the course of the stimulus can be perceived over a certain length ahead, the operator can base his control actions upon this visible future course. The visible length of the future course is the operator's preview. The larger the preview, the more accurately (with an optimum) the task can be performed (Poulton, 1964, 1974).
  In the case of a ship tracking task, the track ahead is either directly or indirectly visible (say through radar) and this enables the ship handler to anticipate the desired track. The effects of preview and the relative weight of various types of preview (view, radar, chart) on ship tracking are not well known. Results from questionnaires show that mariners prefer a combination of outside

view, radar and chart information (Moraal et al., 1973). It can be inferred from Goodwin's (1975) domain theory that preview amounts maximally to approximately 5 L (L = ship's length), because within 5 L ahead of a ship the mutual influence on the paths of ships is noticeable.

* **Perceptual anticipation.** When the course of the stimulus can be inferred from the stimulus movement (speed anticipation), the operator can base his control actions on the inferred future course. Poulton (1952) distinguished between "speed-anticipation" and "anticipating remembered course". Mulder et al. (1976) have labelled these categories as "perceptual" and cognitive" anticipation. According to Mulder et al., cognitive anticipation is exclusively due to memory representations of the stimulus course while, as they suggest, perceptual anticipation concerns both preview (receptor anticipation) and speed anticipation.
  For the ship tracking task it seems useful to consider receptor anticipation separate from speed anticipation. Preview shows the operator the desired track while in case of perceptual anticipation the stimulus course has to be inferred (e.g. inferring the course of other vessels by observing positions at successive time intervals).

* **Cognitive anticipation.** Use of knowledge about the stimulus course is another anticipatory principle and resembles the anticipating of the remembered course (Poulton, 1952; 1957) (see also Magdaleno, 1967) and the cognitive anticipation of Mulder et al. (1976).
  For the ship tracking task, knowledge of the desired track (fairway) is available in the form of chart information or recommendation from an experienced pilot or from the ship handler's own experience.

Preview is extremely relevant in a ship tracking task. Without preview performance is unrealistic. Cognitive anticipation adds knowledge of the fairway characteristics such as current, depth, buoys etc. to the actual preview. Perceptual anticipation plays also a role. It particularly concerns the anticipation of moving objects. However, moving objects are not considered in the present laboratory tracking task.

Preview will of course be affected by the visual cues in the ship's surroundings. Generally speaking, the surroundings contain static and dynamic cues, such as contours, perspectives, textures, brightness, contrasts, perspective movements and movement parallax (e.g. Graham, 1965; Hochberg, 1978). The choice and use of these cues are likely to depend on the type of manoeuvre. For instance, Riemersma (1979) has shown that, when keeping a straight course, car drivers infer lateral displacement from the change of the road perspective. Such data are lacking on the ship tracking task. Although of relevance, these factors will not further be considered in this study.

Summarizing the elements of anticipating a desired track: Preview is of most concern when anticipating, knowledge of the track is additional information. It is assumed that the preview length extends to at least 5 L ahead of the ship. The preview is affected by various visual cues, hence receptor anticipation is dependent on the track's geometry and its markings.

### 2.2.2 The ship's path

Anticipation of the ship's path is conceived of as behaviour based on a prediction of the future system output variables (see also Kelley, 1968). He distinguishes **anticipation by extrapolation** of system output variables from **anticipation by prediction** of system output variables as a result of certain control actions. The anticipation by prediction parallels Poulton's (1957) idea of effector anticipation.

**Anticipation by extrapolation** is only possible when the system output variables are being monitored by the operator. It may be that some or no control actions are taken but it is essential that anticipation is based on the extrapolation of the change of system output state and not as a result of the previous control action. Concklin (1957) has shown for pursuit tasks that operators do indeed use the change of status of a controlled system output variable to check the expected effects of control actions. Gottsdanker (1952; 1957) has shown that the extrapolation of target positions is more accurate when the targets move with constant instead of varying rates. Poulton (1967) has shown that tracking a varying speed of a pointer on a dial improves when its speed is presented on a speedometer (position-display) instead of being shown as a moving pointer only. This finding parallels that of Pew (1966) who showed that targets with a velocity vector are tracked more accurately than those without such a vector. This finding was applied to ship control by Wagenaar (1971). Results of a simulator experiment on the course changes of course-unstable supertankers showed a decrease in course errors when a turn rate indicator was used.

Summarizing the argument so far, monitoring the change of status is a principal element of controlling system output variables. It enables the operator to anticipate the result of control actions. Anticipation is affected by the nature of the status changes and by presentation mode.

**Anticipation by prediction** of process output variables as a result of certain control actions is presumably based on "process knowledge". It is generally accepted that process operators learn relationships between control actions and process output for predicting output as a function of the control setting. The operator's process knowledge is often referred to as an internal model.

Kelley (1968) describes the internal model as a representation of the individual's perception and understanding of his environment, which not only contains the spatial structure of the environment but also incorporates its rules of operation - e.g. temporal, order, and cause and effect relations. The internal model is supposed to develop by trial and error. Veldhuyzen and Stassen (1976) refer to the operator's process knowledge as the Internal Representation covering "some information of the statistics and dynamics of the system to be controlled," necessary for predicting process output. The internal model of the optimal control model (Baron and Kleinman, 1968) is assumed to be a perfect representation of the process dynamics and its disturbances. This assumption is obviously made to prevent a too complex mathematical modelling process (White, 1983). Assumptions about the content and meaning of the internal model notion diverge widely, which limits its use for research purposes. Jagacinski (1978) states that even when an internal model precisely describes the operator's performance, it does not necessarily mean an internal model structure that resembles reality. In general, the internal model concept lacks specificity. Pew and Baron (1978), for instance, indicate the potential of the internal model concept for interpreting human control behaviour, but do not describe any empirical evidence or any testable theoretical specifications. As stated by Willems (1979), an internal model for understanding control behaviour is not useful if it is not further specified and hence not testable. Apparently there is a rather wide gap between (mathematical) internal models **describing** human control behaviour and (predictive) **theoretical** notions on human performance. The internal model is conceived in the present study as the notion that operators can acquire process knowledge to link a desired process status with control settings.

Process knowledge for anticipation purposes seems always to be used in combination with a component for correcting its inaccuracy. On the basis of the results from a ship control study in a simulator (Kraneveld, 1979), Willems (1979) has suggested two components of control behaviour: First, a set of heuristics, acquired by experience concerning relationships between system input variables (e.g. desired outcomes) and control actions (preprogrammed control) and, second, a feedback control mechanism to compensate for remaining errors.

Bainbridge (1981) assumes that the operator's process knowledge is based on conditional propositions about general aspects of process behaviour. The operators perform their task in such a way that they only need to know the direction of the control setting, the approximate gain of control and the lag between control setting and control effects.

A structure of control behaviour that covers the idea of process knowledge and the compensation of control errors has been suggested by Crossman and Cooke (1962). They suppose that operators operate partly in an "open-loop mode" (preprogramming of control actions) and partly in a "closed-loop mode" (see Fig. 2.1).

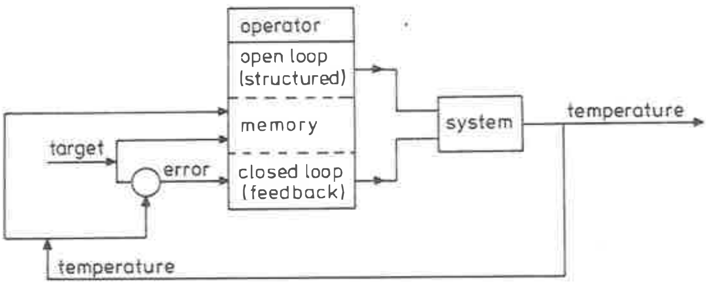


Fig. 2.1 Block diagram showing the elements of an internal model of the operator controlling water boiler temperature (Crossman and Cooke, 1962). It illustrates the idea that a target temperature initiates open and closed-loop control actions, whereas the actual temperature is fed back.

To adjust the temperature at a desired value, the operators use process knowledge in terms of control settings and related temperatures. These relationships are available in memory. Operators learn control patterns in order to change the temperature more efficiently. These chains of control settings are executed without feedback. Feedback control is only used to obtain a more refined process outcome.

It is not clear how and to what degree of accuracy the open-loop element is developed. Crossman and Cooke have suggested that inexperienced operators develop control patterns in a heuristic way. In early training one will primarily deal with keeping the process within limits while gaining as much information as possible about the process. Thereafter, control will be optimized using the developed heuristics. Regarding the above-mentioned studies, it is likely that such heuristics can not be accurate and that optimizing control will therefore remain dependent on feedback. The open-loop element, either rough or accurate, allows the prediction of future states and hence the anticipation of future errors if the desired states are known. As Kelley (1968) states "... manual control systems function to reduce the difference between what an operator wants to happen to a controlled variable and what he thinks is going to happen unless he institutes a change ..." (Kelley, p. 41). Sheridan (1966) and Bainbridge (1978) also assume that expected future errors determine to a certain extent the operator's control actions.

Pew (1974) has suggested that in pursuit tracking **the mode of control** does change as a function of the input signal frequency and subjects shift from **an error correction mode** to a **pattern generation mode**. "... Whereas at lower frequencies he (the subject) was restricted to making corrections on the basis of short-term predictions of the error signal alone, now the error correction mechanism took on a new role, that of assessing the difference between the amplitude, frequency and phase of the sinewave he was attempting to generate and the same parameters of the input sinewave ...". In this view a distinction between an error control mechanism and a preprogrammed control mechanism is related to the input signals. Low frequency input signals (slow tasks) are controlled on the basis of a feedback mechanism. A preprogrammed control element compensates in (rapid) tasks with high frequency input variables the delays of a feedback mechanism and enhances accurate control by means of its open-loop character. Pew's (1974) suggestion bridges the gap between the previously discussed ideas on open-loop (internal model, preprogramming) and closed-loop (error control) elements and the hypothesis on control elements developed in theory on motor learning. In particular, the extensive and elaborated hypotheses of Schmidt (1975) on motor learning seem to match the outlined elements of preprogrammed versus feedback control and rapid versus slow tasks. As this theory is closely related to Adams' (1971) closed-loop theory, which emphasizes the closed-loop nature of motor control and reduces the importance of preprogramming, both theories will be separately discussed in the following section and will be used as an analogy for the ship handler's control performance.

In conclusion, a number of suggestions about the ship handler's control performance can be summarized:

* Preview of the desired task enables the ship handler to anticipate the track ahead (receptor anticipation). Cognitive anticipating adds knowledge of the track ahead to the actual preview.

* A more or less perfect relationship of control settings and their effects is stored in a set of heuristics of memory ("process knowledge"). This "process knowledge" may be conceived of as an internal model or as a control pattern generation element to link a desired process status with control settings.

* "Process knowledge" also enables the operator to anticipate future process status as a function of control settings and seems to be necessary to avoid delay errors in high frequency (rapid) tasks.

* There is a feedback mechanism that utilises the effects of control settings to evaluate an expected deviation from a desired status. The future deviation is anticipated by extrapolation of the perceived status change. This mechanism seems to be essential in low frequency (slow) tasks.

* The "process knowledge" and feedback elements parallel the hierarchical behavioural levels of planning and execution. It is assumed that planning behaviour remains in the cognitive phase of motor learning. The autonomous phase could be reached for corrective control actions.

* It could be that the ship handler is always concerned with the cognitive and associative phase of motor learning, and not the automatic phase.

## 2.3 Hypotheses concerning control behaviour

The notions concerning the ship handler's control performance, as discussed above, parallel the theories of Adams and Schmidt on the acquisition of motor skills in that they contain similar elements for the interpretation of performance. Of course there are also differences between controlling ships and limbs. The resemblance, however, justifies a more detailed discussion of motor learning theories.

According to Adams (1971) the acquisition of motor skills depends on two components: a memory and a perceptual trace. The **memory trace** can be defined as a modest motor program that only chooses and initiates the individual's response rather than controlling a longer sequence of movements. The memory trace must be cued to action and its strength grows as a function of practice. Its strength is also a function of stimulus-response contingency. The **perceptual trace** evaluates the correctness of the response as initiated by the memory trace. The perceptual trace is a reference trace, based on the storage of past movements. Starting a movement brings about an anticipatory activation of the perceptual trace with which the feedback from the ongoing movement is compared. The strength of the perceptual trace grows as a function of the experienced feedback on each trial.

Adams' theory is based on data obtained in an acquisition of linear self-paced aiming movements. The first stage of the acquisition is supposed to be under verbal cognitive control (cognitive phase) and to depend on knowledge of results (KR) as the only possibility for subjects to correct errors. Information extracted from KR is used to avoid errors in the next movement. At the same time it is essential to the initial build-up of the perceptual reference-trace. After training only small errors remain; the perceptual traces converge. In a following learning stage (associative phase), performance gradually becomes independent of KR and the perceptual trace functions as a reference for the correctness of the movement. In that stage subjects can make correct responses over and over again and still strengthen the perceptual trace. Learning under the latter condition has been called subjective reinforcement (Adams, 1971). In this motorstage condition where KR is no longer needed, Adams (1971) suggests that conscious movement control has become automatic (autonomous phase).

The theory relies heavily on response recognition but principally consists of two elements "... If the agent that fires the response also is the reference against which the response is tested for correctness, the response must necessarily be judged as correct, because it is compared against itself. Response activation and evaluation requires an independent mechanism ..." (Adams, 1971, p. 125).

This two-component-notion is further specified in Schmidt's (1975) schema theory, in particular with regard to differences between rapid and slow movement tasks. This distinction between rapid and slow movement tasks was made by Schmidt and is inferred from his theory since the two components are conceived of as compensating each other's limitations. A **recall schema** is viewed as a centrally controlled motor program for preprogramming control in rapid movements, while a **recognition schema** is viewed as a response evaluating control element based on peripheral feedback and needed in slow movements.

Schema theory can be briefly described by mentioning four essential elements that are learned when making goal-oriented movements. Schmidt (1982) assumes that after a movement is carried out by a generalized motor program, the subject stores four elements:

* The initial conditions (body positions, weight of thrown objects, etc.) that existed before the movement.

* The parameters that were assigned to the generalized motor program.

* The outcome of the movement in the environment in terms of KR.

* The sensory consequences of the movement (how the movement felt, looked, sounded etc.).

These four sources of information are not stored permanently but only long enough for the performer to abstract some relationships from them. Schmidt's schema theory contains two such relationships (schemata). These two schemata represent two states of memory: a **re-**

**call memory** - consisting of recall schema - that is responsible for the production of movements and a **recognition memory** - consisting of recognition schema - that is responsible for response evaluation. For rapid ballistic movements, recall memory is involved with the motor programs and parameters, structured in advance to carry out the movement, but with minimal feedback involvement. Recognition memory, on the other hand, is a sensory system capable of evaluating the response-produced feedback after the movement is completed, thereby informing the subject about the amount and direction of any errors in responding. For slow movements, the recall memory is not thought to play an important role. During the actual slow movement response produced feedback is continually compared with the reference of correctness. In these slow movements, the recall state merely pushes the limb along in small bursts and stops when the response-produced feedback and the reference of correctness match.

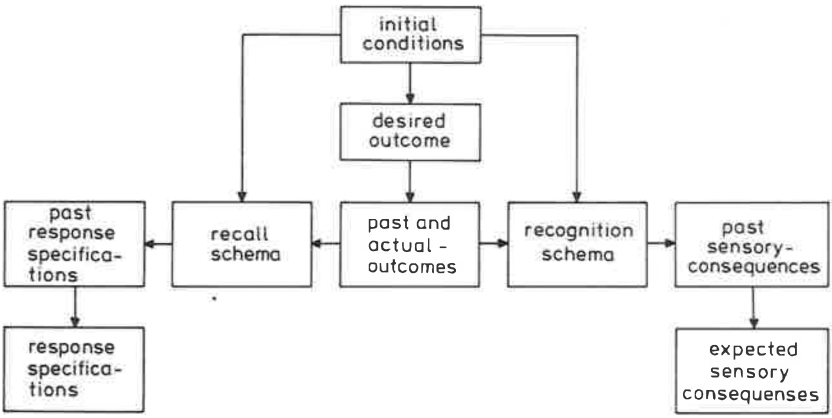


Fig. 2.2 This diagram (Schmidt, 1975) illustrates that response specifications and expected sensory consequences are produced making use of information on initial conditions and desired outcome. The recall and the recognition schema relate information and production.

The schemata constitute the body of Schmidt's theory with emphasis on the idea of generalized motor programs. Movement parameters for specifying a particular way of executing a motor program are rule based (see Fig. 2.2).

The production of movements is assumed to be based on the recall schema. Schmidt (1982) suggests that when an individual produces a movement the brief storage of the parameter and the movement outcome produces a "data point", which can be presented on a graph (see Fig. 2.3a). With repeated responses using different parameters and producing different outcomes, other data points are established, and the individual begins to learn a relationship between the size of the parameter and the nature of the movement outcome.

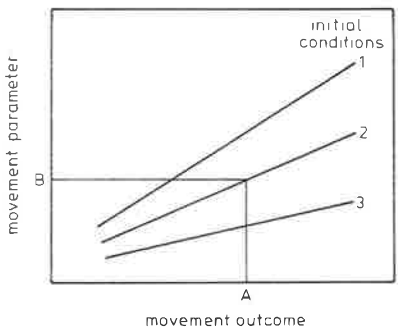


Fig. 2.3a The recall schema: the hypothetical relationship between movement outcomes in the environment and the parameters that were used to produce them for various initial conditions (Schmidt, 1982). The desired outcome A produces the movement parameter B for initial condition 2.

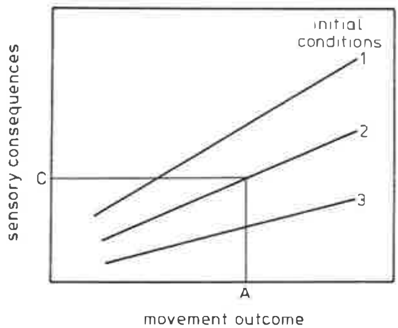


Fig. 2.3b The recognition schema: the hypothetical relationship between movement outcomes in the environment and the sensory consequences produced for them by various initial conditions (Schmidt, 1982). The desired outcome A produces the sensory consequence C for initial condition 2.

After adjustments on the basis of KR a rule is established relating parameters and outcomes. Principally, the nature of KR in this case is one of **guidance** (Salmoni et al., 1984) since KR provides information about the **response outcome**. The subject uses this information to generate a new response on the next trial which is more accurate than the previous one and hence performance improves as a function of the number of KR trials.

The recognition schema for response evaluation is thought to be formed and used in a similar way as the recall schema. After each trial, the relationship among initial conditions, outcomes and sensory consequences converges to a rule.

The recall and recognition schemata are thought to be used in an analogue way. Given the initial conditions and the specific desired movement outcome (A), the individual decides, prior to the response, to specify the response parameter (B) and the sensory consequence (C).

For rapid movements, performance is primarily based on the recall schema; sensory consequences are compared to their expected states; any difference in the final outcome represents an error which is labelled and is then delivered back to the information processing mechanisms as subjective reinforcement.

For slow movements, the theory says that subjective reinforcement is actually used to produce the action. Hence, the expected feedback sources represent the criterion of correctness and the feedback compared to them gives on-going information about errors during the response.

The main differences and similarities between Adams' closed-loop theory and Schmidt's schema theory have been extensively described by Schmidt (1975; 1982). Here the distinctions and similarities are briefly reviewed with regard to the notions mentioned earlier, on the ship handler's performance (see Table 2.1).

A major difference between Adams' closed-loop and Schmidt's schema theory concerns the extent of preprogramming of responses (open-loop control). Adams' memory trace predicts inaccurate preprogramming because this trace is conceived of as a "modest motor program" that only chooses and initiates the direction of action. It is rather different from Schmidt's recall schema and the internal model notion. These latter two hypotheses predict accurate preprogramming of responses by rules (recall schema) or by a representation of the process dynamics (internal model).

A major similarity between Adams' and Schmidt's theory is the correctness reference and the distinction between an element for generating responses versus an element for evaluation of control outcomes. This reference trace and this distinction between two components is not provided by the internal model notion and lead to an inconsistency in that notion. When the internal model determines the response and is also a reference of its correctness, the response must necessarily be judged as correct, because it is compared against itself. The only reference in the internal model concept is the desired outcome. During the movement there is only a subjectively judged guidance (the internal model) to provide error information. This argument puts the internal model in the role of a recall schema.

Another distinction within these theories is the role of subjective reinforcement in rapid and slow tasks.

Schmidt (1975) has provided evidence (Schmidt and Russell, 1972; Schmidt and White, 1972) that subjective reinforcement (SR) (error information generated by the subject), is only effective in rapid movement tasks because of the opportunity proved of checking the movement again, by objective error information (KR) and with subjective interpreted feedback information.

Adams did not make a distinction between rapid and slow movement tasks with regard to SR. According to Schmidt, however, these two types of tasks should be distinguished with regard to SR. It is reasonable to assume that in ship tracking dividing into slow and rapid movement tasks is also meaningful. This issue is discussed in Chapter 3. As a consequence of this distinction, accurate performance of a slow movement task depends on the development of an accurate perceptual trace or recognition schema, based on KR as indicated by Adams and Schmidt.

There are further differences between Schmidt's and Adams' theory, such as the explanation of the way in which novel responses are acquired. Within the present context, the effects of target variability on practice is worthy of comment. Adams' theory predicts that, when the learner is faced with a number of targets centred around a criterion target, practice should be less effective than continuing practice at the target itself. The reason is that with variable targets incorrect movements do not strengthen the perceptual

Table 2.1 Overview of notions concerning human operator's performance components. This overview shows that the ship handler's performance hypotheses contain elements of both Adams' and Schmidt's theories. The disctinctions between rapid and slow tasks and between knowledge of results (KR) and subjective reinforcement (SR) for learning are based on Schmidt's theory.

| Theory | Performance components | | Type of task | | Learning | |
|---|---|---|---|---|---|---|
| | Response selection (control setting) | Evaluation of effect of control (outcome) | Rapid | Slow | Cognitive phase | Autonomous phase |
| Adams' closed-loop theory | Memory trace | Percept-ual trace | No distinction Primarily perceptual trace based perform-ance | | By KR and SR. Practice in specific conditions | With SR (or KR) learning is continued |
| Schmidt's schema theory | Recall schema | Recognition schema | Primarily recall-based performance | Primarily recognition-based performance | By KR and SR for rapid tasks, by KR for slow tasks Practice in a variability of conditions | With SR (or KR) learning is continued in rapid tasks Without KR learning in slow tasks is not continued |
| Internal model notion | Internal model | Future error between desired and predict-ed effect | No distinction Internal model based performance | | By trial and error (by KR?) | Not defined |
| Ship handler's perform-ance hypotheses | Motor memory Alterna-tives: global or accurate | Perceptual memory Alternatives: specific or general | Primarily motor memory based performance | Primarily perceptual memory based performance | By KR and SR for rapid tasks, by KR for slow tasks | With SR (or KR) learning is continued in rapid tasks Without KR learning in slow tasks is not continued |

trace which is strictly and associatively bound to the criterion target. Schmidt's theory, on the other hand specifically predicts efficient learning with target variability because of the notion of the rule-based general motor program. Adams' perceptual trace is uniquely developed for each specific movement while Schmidt's recognition schema is a functional rule that allows extrapolation.

These theories and notions on control behaviour for aiming movements along a line can now be easily transformed into a theory on control behaviour for movements of a ship along a track.

It is hypothesized that the ship handler develops a **motor memory** (either a memory trace or recall schema) and a **perceptual memory** (either a perceptual trace or recognition schema). The motor memory contains the relationships between initial conditions, desired and past outcomes and rudder deflections. The perceptual memory contains the relationship between initial conditions, past system outcomes and ship movements (see Fig. 2.4) as perceived by the ship handler.

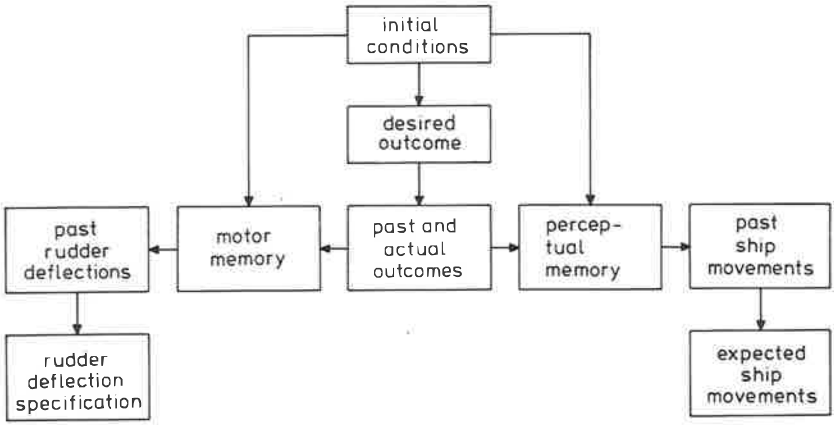


Fig. 2.4 This diagram illustrates that rudder deflection specifications and expected ship movements are produced making use of information on initial conditions and desired outcomes. The motor memory and the perceptual memory relate information and production.

In **slow movements**, the perceptual memory is dominant. The subjects carry out motor memory-based rudder deflections. After watching the resulting ship's movements, they compare expected and actual movements. The role of the motor memory is to produce small adjustive movements which are subsequently controlled by the perceptual memory by comparing expected and actual outcomes. In early learning, track completion depends fully on KR because this provides the only means through which the subjects are informed about deviations between desired track and travelled path. Without KR performance does not improve, since the schema cannot develop. If KR is withdrawn after a training period, performance remains at the same level because the correctness of the travelled path cannot totally be inferred from the final position reached, but needs KR about the path itself.

In the case of **rapid movements**, where performance is mainly based on motor memory, tracking accuracy also depends on KR in the early learning stages because motor memory as well as perceptual memory are built. After training, subjective reinforcement can improve performance because the correctness of the travelled path can be inferred from the final position.

The **motor memory**[1] covers the open-loop character of the internal model notion and of the recall schema.

With regard to the ship handler's performance, however, there is no empirical evidence that the motor memory consists of an accurate relationship between initial conditions, desired outcomes and rudder deflection. As mentioned before, Bainbridge (1981) even suggests an inaccurate relationship. Since theories assume that there is either an accurate or inaccurate motor memory, two alternative hypotheses can be formulated. **A motor memory conceived of as an internal model or recall scheme assumes an accurate relationship, while such a motor memory conceived of as a memory trace assumes an inaccurate relationship between initial conditions, desired outcomes and rudder deflections.**

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[1]The motor memory is not a motor program with a prestructured set of central muscle commands but viewed as a cognitive motor program, parallel to Schmidt's recall schema, involved with the production of control actions.

The motor memory hypothesis has to be made explicit with regard to tracking and to specific ship's aiming movements. First, novices without any ship control experience should show increasing accuracy of tracking with increasing practice, indicating a motor memory development. Second, specific aiming movements should show an increase in aiming accuracy in order to comply with the accurate motor memory hypothesis. It would also be advantageous for the recall schema hypothesis (and consequently for the internal model notion), to consider conditions providing variability of target positions.

The **perceptual memory** covers the reference trace idea of Adams' and Schmidt's theory for evaluating the correctness of perceived process outcomes in the environment.

Concerning the ship handler's performance there is no empirical evidence that confirms perceptual memory. **A perceptual memory conceived of as a perceptual trace assumes an accurate relationship between initial conditions, expected ship movements in the environment and desired outcome as a set of unique stimulus-bound relations. Conceived of as a recognition schema it assumes an accurate relationship based on a rule between initial condition, expected ship movements in the environment and desired outcomes.**

The perceptual memory hypothesis has to be made explicit with regard to specific tracking conditions. First, novices without any ship control experience should show increased tracking performance with increased practice, indicating a perceptual memory development. Second, with variability of target positions, practice effects should confirm the recognition schema hypothesis while effects without variability should confirm the perceptual trace hypothesis.

The perceptual memory seems to match the notion of Concklin (1957) extremely well. Immediate presentation of control effects relative to a reference enables the operator to extrapolate a possible deviation with regard to that reference and to correct the control setting. The perceptual memory reveals the tracking error for the operator and provides a means for anticipation.

The organization of the ship handler's control behaviour can now be considered from the preprogrammed control viewpoint and from the feedback control viewpoint.

The preprogrammed control emphasizes the planning of behaviour based upon a **motor memory**. Control execution is primarily oriented at future targets. The preview of the desired track (targets) defines the initial conditions and the desired outcomes and acts as system input to link stimuli with patterns of control actions. The perceptual memory plays no role of importance.

The feedback control viewpoint emphasizes the planning of behaviour based upon a **perceptual memory**. Deviations from a performance reference are continuously reduced by an imprecise operating motor memory. It is assumed that the error between expected (by the perceptual memory) control effects and the effects to be realized are anticipated by means of extrapolation of the status change.

In conclusion, a number of hypotheses and expectations on the ship handler's control performance can be summarized:

* Preview of the desired track enables the ship handler to anticipate the track ahead. It defines the initial conditions and the desired outcomes in the ship's environment. The track may be viewed as a set of position references which helps to constitute a perceptual memory.

* A motor memory as a recall schema or an internal model **predicts**, after practice, an accurate rudder selection as a function of initial conditions, past and desired outcomes. Performance in rapid movement tasks depends primarily on this motor memory.

* A perceptual memory as a perceptual trace or a recognition schema **predicts**, after practice, accurate performance on the basis of feedback. The perceptual memory contains a set of correctness references for evaluating system outcome. Deviations between expected ship movements in the environment and actual predicted ship movements, may be viewed as future error to be anticipated by extrapolation of the perceived status change of the error. Performance in slow tasks depends primarily on perceptual memory. A motor memory in such tasks acts as a memory trace and **predicts** inaccurate rudder selection.

* In rapid movement tasks control behaviour **needs** to be based on a motor memory and is acquired by knowledge of results, whereas learning can be extended with subjective reinforcement.

* In slow movement tasks control behaviour **primarily needs** to be based on a perceptual memory and is acquired by knowledge of results, whereas learning cannot be extended with subjective reinforcement.

* Motor memory conceived of as a recall schema, and perceptual memory conceived of as a recognition schema, **predicts** effective learning with a variability of targets while a perceptual memory conceived of as a perceptual trace **predicts** effective learning on specific targets.

* In slow movement tasks the planning of control behaviour could be based on perceptual memory and the executing level on motor memory. In rapid movement tasks planning and execution could be based only on a motor memory.

* It is assumed that the ship handler's control behaviour remains in the cognitive phase of motor learning for planned actions of major ship movements. The autonomous phase could be reached for corrective control actions.

Hypotheses on the components of control behaviour in ship tracking will be tested in a laboratory tracking task within a tracking task paradigm (Chapters 3 and 6) and within a stimulus-response paradigm (Chapters 4 and 5). In Chapter 3 emphasis is laid on generalization of results while the Chapters 4, 5 and 6 the hypotheses are tested within a theoretically constrained framework.

# 3 SYSTEM PERFORMANCE MEASURED BY FORCING FUNCTIONS

## 3.1 Forcing functions as tracking tasks

In reality a ship handler need not always precisely pursue an intended track. Assuming an intended track, drawn on a radar display or on a chart as is recommended by passage planning procedures (DT, 1980; Spaans and Goldsteen, 1983), there should always be an indication of the areas which leave the mariner a certain available manoeuvring space. The necessity of accurate track-keeping seems therefore always to be weighed against the available manoeuvring space, depending on, for instance, the fairway geometry, the weather, the sea conditions and visibility (IMCO, 1972).

To distinguish between the operator's ability to pursue an intended track and to weigh available and needed manoeuvring space against performance criteria such as safety and speed, a procedure is proposed that primarily reveals the system performance (piloted controllability) relative to the inherent controllability of the vessel itself. In order to determine the ship handler's proficiency of pursuing tracks per se, it is proposed that the ship's path resulting from zig-zag manoeuvring tests be used as a forcing function. In that case the available manoeuvring space is artificially removed while the need to base control behaviour on either a motor or a perceptual memory can be manipulated by varying the zig-zag-test-based forcing functions, as is specified in the following sections.

The zig-zag manoeuvring test mainly reflects the control characteristics of the vessel (Mandel, 1967). This type of test is performed at a constant initial forward velocity. Heading changes are the result of preselected rudder deflections. When a predetermined heading change is completed an opposite deflection is carried out until the new heading change equals the opposite of the earlier one. The predetermined deflections are reproduced several times. The resulting ship's path is approximately a sine-wave track. The ship's forward speed decreases and fluctuates around a mean value lower than the initial speed (see Fig. 3.1).

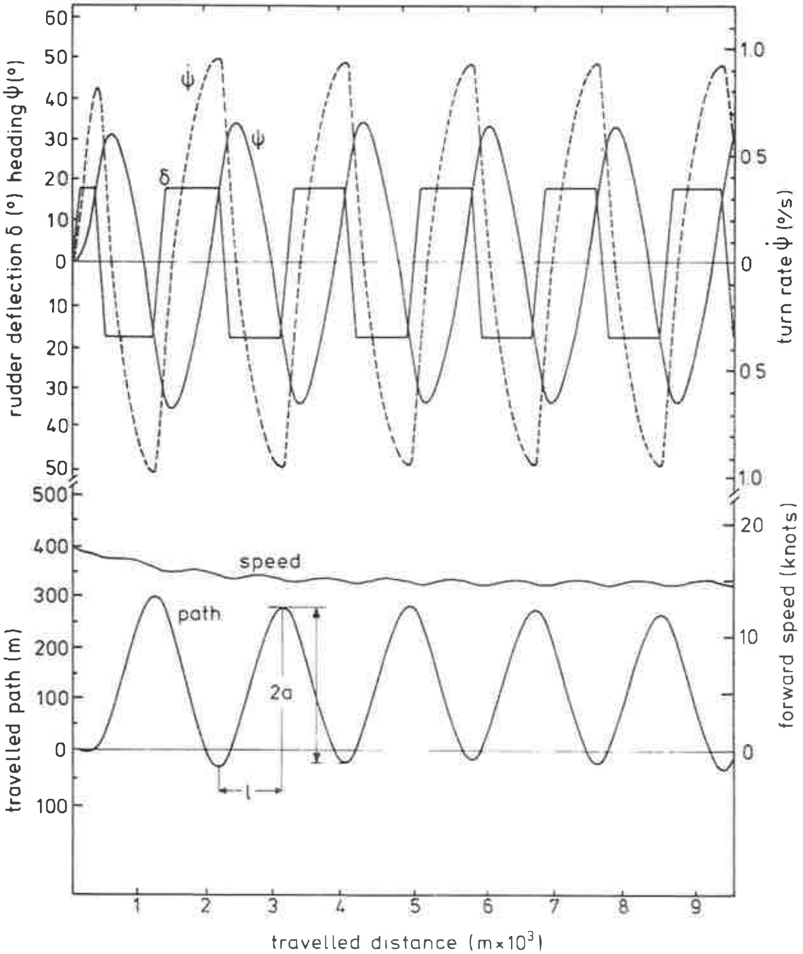


Fig. 3.1 Results of a zig-zag manoeuvring test.

When a similar sine-wave track is presented to the ship handler as a forcing function (desired track), the size of the tracking error reveals the ship handler's track keeping ability relative to the ship's manoeuvring characteristics and not to the fairway geometry. It offers the opportunity of testing the ship handler's ability as a function of the period of the sine-wave, and of determining the limits of that ability.

A hypothetical relationship between the correctness of tracking performance and the various forcing functions is presented in Fig. 3.2. The inherent controllability represents the manoeuvring capacity of the vessel and the piloted controllability is expressed as a correctness score between zero and one. The various forcing functions are defined by an index of the amplitude/period length ratio.

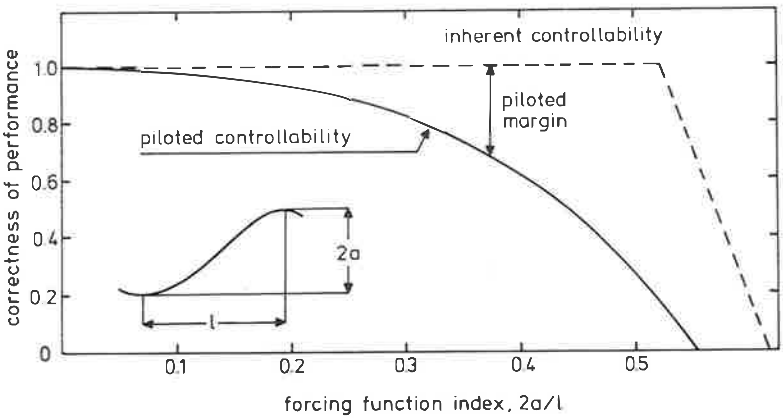


Fig. 3.2 Hypothetical relationship between correctness of tracking performance and various forcing functions. The forcing functions are defined by an index of amplitude-/period length ratio.

Tracking error is inevitable when the forcing function demands larger rudder deflections than are maximally available. Hence, at a forcing function index (FFI) stemming from forcing functions with rudder deflections larger than maximal, the inherent controllability is insufficient and leads to incorrect performance. At the forcing function index based on the maximal rudder deflection, the **limit** of piloted controllability (system performance) and inherent controllability is reached. At that index the **only correct sequence of control settings** is that which with deflections in time and magnitude **produces** the forcing function. At forcing functions with lower indexes there is an increasing possibility of correcting errors in control settings.

The forcing function based on a zig-zag manoeuvre with maximal rudder deflection represents a track with no latitude for error. The slightest deterioration in the ship handler's sensing, information processing or motor activities shows up as a tracking error. In terms of the earlier discussions, this extreme forcing function represents a **rapid task**[1] because the operator's control behaviour has to be based on open-loop control such as a motor memory to avoid errors of peripheral feedback delays.

When a forcing function stems from a zig-zag manoeuvring test with less than maximal rudder deflections, this function represents a **slow task**[1] since it provides the ship handler with the opportunity of correcting errors so that performance can be controlled by perceptual memory. The role of motor memory is presumably limited to the production of small initial movements.

It is hypothesized that performance on forcing functions with low indexes will primarily depend on perceptual memory. On forcing functions with high indexes performance will still depend on perceptual memory but contributions of motor memory will be increasingly important so as to minimize incorrect control settings. Hence, slow tasks represented by forcing functions with low indexes decrease the importance of motor memory while such tasks represented by forcing functions with high indexes increase that importance. A rapid task is conceived of as a special case of a slow task; preprogrammed control actions are demanded and feedback control is useless for accurate performance.

The forcing function procedure resembles the laboratory tracking task. The system performance is conceived of as the outcome of the ship handler's control actions based on human/machine interfaces, the ship's characteristics and the environmental conditions and will be indicated relative to an externally-programmed system input signal. The operator's fundamental requirement is error nulling. The results can be generalized to real-life manoeuvring conditions. However, performance in tracking tasks provide fewer means for stringent tests than performance shown by a single control action with limited task and environmental variables and investigated within a stimulus-response paradigm (Chapters 4 and 5).

It is to be expected that, in contrast with novices, experienced ship handlers will have a motor memory available which allows for

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[1]In the present study rapid and slow tasks are defined relative to the ship's responses on control actions and not to the human's reactions on stimuli.

minimal tracking-error in a rapid task. Slow tasks should show equivalent performance of novices and experienced mariners, since performance accuracy is supposed to depend mainly on perceptual memory, which has to be developed by both groups due to the novel artificial zig-zag surrounding.

Wylie (1976) suggests that experienced ship handlers perform ship manoeuvres primarily by extrapolating the ship's position changes (see also Hinsch, 1978). He argues that due to the differing characteristics of outside view and radar, in particular with regard to the feedback of ship's position changes, manoeuvring performance is degraded in radar conditions. Position changes are presented on radar as a bird's eye view but with discrete displacements of ship surrounding targets. Each target position is updated after two and a half second. Although such displacements can be perceived as motion (Wagenaar, 1984), it is reasonable to assume that at low speeds these displacements are below the threshold of visual acuity for some periods of time. The effects of a bird's eye view and a perspective view in a road traffic situation were analysed by Spenkelink (1985) (see also Ebbesen et al., 1977). Results of an experiment on pedestrians' decisions in crossing a road when a car approaches, showed that with the bird's eye view decisions were taken on speed and distance information and with the perspective view on temporal information. Hence, if a bird's eye view is presented by radar, the discrete presentation of position changes may be hampered if these changes approximate the threshold of visual acuity. Thus it can be expected that in slow radar tasks, performance is degraded because of degraded feedback, whilst in conditions with outside view on the ship's surrounding movement feedback is minimally degraded. In a rapid task, the motor memory hypothesis predicts an equivalent performance in view or radar conditions since feedback can play no role assuming that preview is adequately presented by radar as well as view.

In Experiment 1 the motor and perceptual memory hypothesis and in Experiment 2 Wylie's suggestion on feedback is tested.

## 3.2 Experiment 1: Comparison of performance by pilots and by students

### 3.2.1 Introduction

In this experiment, system performance with a 40,000 ton container vessel was determined as a function of pilots' and students' control behaviour. The subjects were asked to track various forcing functions which were visible through the bridge windows. Preview was provided over two tops of the sine-wave-shaped forcing functions, so that accurate tracking was possible with regard to the system input variable (Poulton, 1974).

In **slow tasks**, it is expected that pilots and students will perform approximately the same because the perceptual memory concerning these artificial fairways has as yet to be developed by both groups. Pilots, however, will have the advantage of a developed motor memory and therefore will perform slightly better than students. The slower the task, the less pronounced this advantage will be because of the increasing possibility of correcting control actions and the increasing importance of the perceptual memory for accurate performance. In faster tasks, the advantage will be more pronounced since it is likely that pilots do not need to correct control actions to the same extent as students because of the available motor memory. Both groups are likely to show a pronounced performance improvement as a function of practice because of the development of perceptual memory. Subjects are, themselves, supposed to acquire knowledge of results, because they can infer the accuracy of the travelled path to a certain extent from their position on each top of the forcing function.

In **rapid tasks**, control behaviour has to be based on a motor memory if accurate manoeuvring is required. It is expected (par. 2.3) that in rapid tasks pilots will show less tracking error than students, because of the expected availability of a motor memory, developed by the pilots as a function of experience. In particular students should improve their performance as a function of practice because their motor memory will be developed on the basis of SR and KR, provided by the outcome of each individual control action.

In order to compare performance on forcing functions with performance in less restricted manoeuvres at sea, the standard deviation of the rudder deflection will be used as a rough measure to indicate the amount of inherent controllability needed. Gates and Herbich (1978) have pointed out, on the basis of interviews with pilots and of the results of simulator experiments, that manoeuvres at sea can be categorized by means of the standard deviation of the rudder deflection. Manoeuvres with a standard deviation of less than 10° are considered as normal and those with deviations between 10°

and 20° as representing emergency handling. Manoeuvres with larger standard deviations are beyond the limits of pilot's ability to control a ship. Results of some trials at sea confirms this categorization. From ten 30°-course changes with tankers (RWS, 1976) and thirty-four 60°-course changes with push-tows (RWS, 1979) it also appeared that in normal manoeuvres the rudder deflection standard deviation amounts to approx. 10°. Hence, performance on forcing functions can be compared to performance in real-life by means of the standard deviation of the rudder deflection.

### 3.2.2 **Method**

**Subjects**

Six pilots and six university students served as subjects. The pilots had just left the active service. Their age varied between 55 and 58 years. They were practised in the conning of all types of vessels. The students were 20-25 years old and had no experience with ship control. All subjects had normal or corrected-to-normal vision.

**Task**

The subjects were asked to conn a 40,000 ton container vessel by means of continuous rudder control (see Appendix I) as accurately as possible along four forcing functions. The ship travelled at a constant initial forward speed of approximately 19 knots. The forcing functions were visible through the windows of the bridge mock-up (View). Navigational instruments could not be used.

**Experimental design**

In a split-plot factorial design the variable experience was varied between groups (GR, pilots and students). Forcing function (FF, 4 levels) and replication (RE, 5 levels) were varied within groups. The testing order was balanced.

**Instrumentation**

A subject was seated at the center window of the bridge mock-up of the simulator (see Appendix I) and had a tiller for rudder control. The rudder could be deflected maximally over 35°. A force of 7 N was needed to move the tiller from the 0°-position and otherwise the force amounted to 3.5 N. The gain ratio between tiller and rudder deflection amounted to 2:1 (Stuurman, 1975; Underwood and Buell, 1975). A rudder angle indicator showed the rudder angle deflection with an accuracy of one degree.

The fairway, approximately 1000 m wide, was marked by dikes. Each top of the forcing function was indicated by the centre of a 200 m wide opening in a dike, perpendicular to the fairway axis (see Fig. 3.3). The forcing functions were defined by an index of the ratio of the double amplitude (333 m) and the half of the period length (l). The indexes amounted to 0.250; 0.375; 0.438; 0.500. Each trajectory was marked by 10 openings.

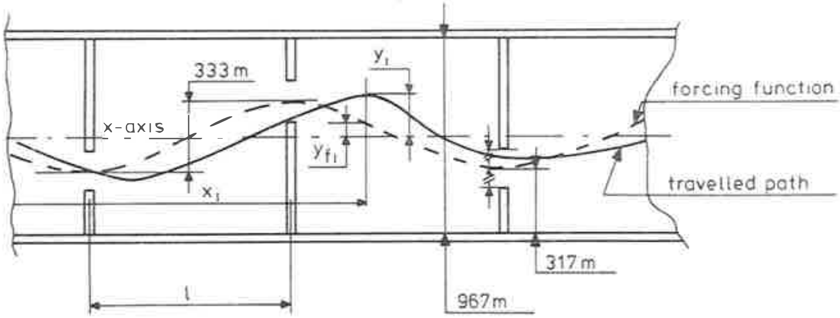


Fig. 3.3 Groundplan of a part of the fairway (1000 m wide) with dikes perpendicular to the fairway axis, indicating the tops of the forcing function.

The eye height of the subjects was located at 25 m above the sea surface. The dikes were 20 m high. The subjects could see at least two openings ahead (see Fig. 3.4).

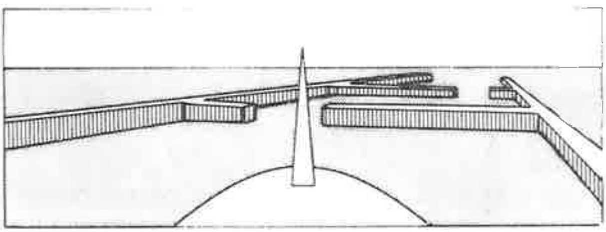

Fig. 3.4 A forcing function visible through the windows of the bridge mock-up. Each top of the forcing function is indicated by the centre of a 200 m wide opening in a dike perpendicular to the fairway axis. In the foreground the mast and the forward deck are visible.

**Training and instruction**

Subjects were familiarized with the ship dynamics by performing zig-zag manoeuvres and course changes, displayed on a compass, turn rate and rudder angle indicator. They were familiarized with the forcing function by means of a practice trial on forcing function index 0.250.

The subjects were asked to follow a sine-wave track by passing the centre of the openings with a heading parallel to the fairway axis. The ship's path between the openings should be as smooth as possible. Large rudder deflections were to be avoided. These instructions provided the conditions which were designed to produce a sine-wave track.

**Procedure**

Each subject was tested on two successive days. On first day subjects were familiarized and instructed, which took about two hours. This was followed by three blocks of trials. Each block containted one trial on each of the four forcing functions. The next day continued with two further blocks of trials.

A trial of one forcing function took approximately 25 min. There was a rest of 5 min. between successive trials and a lunch of half an hour.

A trial was stopped when the ship collided with a dike.

**Scoring and analysis**

**Completed trials** A trial was stopped when the ship collided with a dike. The number of completed trials was counted as an overall measure of performance quality. Uncompleted trials were ignored.

**Tracking performance** The deviations between the forcing function and the actual travelled path were indicated by the root-mean-squared error (RMS), by the phase-shift of forcing function and travelled path ($l_x$) and by the amplitude-ratio ($\alpha$) of both curves.

**RMS-error** indicates the tracking error and can be conceived of as the standard deviation of the travelled track relative to the desired track (Poulton, 1976; Kelley, 1969) under the assumption that the mean tracking error is zero (see Fig. 3.3).

$$\text{RMS-error} = \sqrt{\frac{\sum_{i=1}^{n} \left[y_{fi} - y_i\right]^2}{n}} \text{ in meters}$$

with i = $i^{th}$ sampling interval; length of the interval amounted to 50 m

n = total number of samplings

$y_{fi}$ = function value of the forcing function at interval i, 166,5 sin $(2\pi/l_f \cdot x_i)$ in meters

$y_i$ = function value of the travelled path measured as the distance between subject's position perpendicular to the fairway's axis at interval i in meters

$l_f$ = length of one period of the forcing function in meters

$x_i$ = distance from origin on the x-axis at sample i in meters.

**Phase-shift** ($l_x$) indicates the shift in x-axis direction from the travelled path (subject's position on the bridge) to match maximally the desired track.

**Amplitude-ratio** ($\alpha$) indicates the ratio of the amplitude of the travelled path and the desired track.

Phase-shift and amplitude-ratio were computed by standard Fourier series techniques.

$$l_x = \tan^{-1} (C_p / S_p) \cdot \frac{l_p}{2\pi} \qquad \alpha = \frac{2\sqrt{C_p^2 + S_p^2}}{a}$$

The input signal $y_{fi}$ at interval i is given by

$$y_{fi} = a \sin (2\pi/l_p \cdot x_i)$$

a = 166.5 m, the amplitude of the forcing function.

The Fourier series coefficients of the output $y_i$ at frequency $2\pi/l_p \cdot x_i$ are given by

$$C_p = \frac{1}{n} \sum_{i=1}^{n} y_i \cos \left(\frac{2\pi}{l_p} \cdot x_i\right) \qquad S_p = \frac{1}{n} \sum_{i=1}^{n} y_i \sin \left(\frac{2\pi}{l_p} \cdot x_i\right)$$

with i = $i^{th}$ sampling interval; length of the interval amounted to 50 m

n = total number of samplings

$y_i$ = function value of the travelled path, measured as the distance between subject's position perpendicular to the fairway's axis at interval i in meters

$l_p$ = length of one period of the sine-wave p in meters
$x_i$ = distance from origin on the x-axis at sample i in meters.

**SD rudder deflection** ($\sigma_\delta$) The standard deviation of the rudder deflection was calculated to indicate the extent to which the inherent controllability (max. rudder deflection) was approximated.

$$\sigma_\delta = \sqrt{\frac{\sum_{i=0}^{n} (\delta_i - \bar{\delta})^2}{n}} \text{ in degrees}$$

with i = $i^{th}$ sampling interval; length of the interval amounted to 50 m
n = total number of samplings
$\delta_i$ = rudder deflection at sample interval i in degrees
$\bar{\delta}$ = mean value of the rudder deflection in degrees.

The completed trials were subjected to a Mann-Whitney U-test to analyse performance differences between groups. In order to determine the effects of forcing functions, the scores of each subject for each forcing function were summed over replications. A Friedman two-way analysis of variance was carried out whereby each subject was considered as a sample. The effect of replications was determined in the same way. The interactions between groups and forcing functions, respectively replications were tested with a Kolmogorov-Smirnov test. Effects of replications within groups at individual forcing functions were tested by the Cochran Q-test (Siegel, 1956).

Tracking performance scores were subjected to an analysis of variance (ANOVA). These scores were, because of the large number of interrupted trials due to dike collisions, **only** analysed for the data of the **fifth replication** of the forcing function indexes 0.250, 0.375 and 0.438.

### 3.2.3 Results

**Completed trials; n-scores**

The Mann-Whitney U-test showed a significant difference between groups ($U = 5$; $p < .05$). Pilots completed 91 and students 68 trials, summed over all conditions. There was no significant interaction between groups and forcing functions (Kolmogorov-Smirnov, n.s.). There was a significant difference between forcing functions ($\chi_r^2$ = 28.6; $df = 3$; $p \ll .01$). The summed number of completed trials decreased as a function of increasing forcing function index. A Mann-Whitney U-test on performance of groups for the individual forcing functions showed that pilots completed significantly more trials than students at FFI 0.438 ($U = 5$; $p < .05$) and not FFI 0.500 ($U = 10.5$; n.s.), at FFI 0.375 ($U = 10.5$; n.s.) and at FFI 0.250 (see Fig. 3.5).

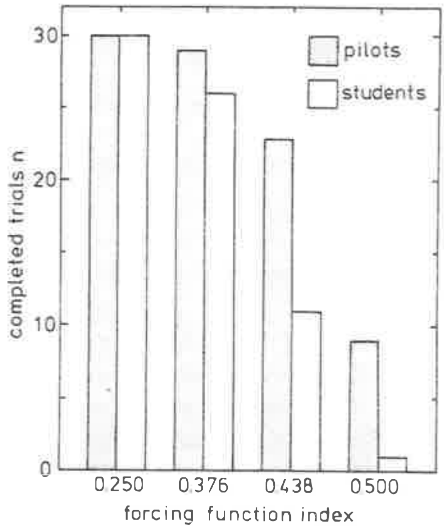


Fig. 3.5 The number of completed trials as a function of groups and forcing functions, summed over subjects and replications. The maximal number of n amounts to 30 per group on each forcing function.

A Friedman two-way analysis of the replications revealed a significant effect of practice ($\chi^2_r = 14.2$; df = 4; $p < .01$). There was no significant interaction between groups and replications (Kolmogorov-Smirnov, n.s.). A further analysis of practice effects within groups showed a significant effect of practice in the group of students ($\chi^2_r = 9.55$; df = 4; $p < .05$) and not in the group of pilots ($\chi^2_r = 5.49$; df = 4; n.s.). An analysis of practice effects within groups at individual forcing functions by means of the Cochran Q-test showed only a significant effect of practice for students at FFI 0.375 ($Q = 9.7$; df = 4; $p < .05$). The other combinations of groups and forcing functions delivered no significant effects (Pilots: FFI

0.250, Q = 0; FFI 0.375, Q = 4; FFI 0.438, Q = 8.4; FFI 0.500, Q = 8.5. Students: FFI 0.250, Q = 0; FFI 0.438, Q = 9.0; FFI 0.500, Q = 0) (see Fig. 3.6).

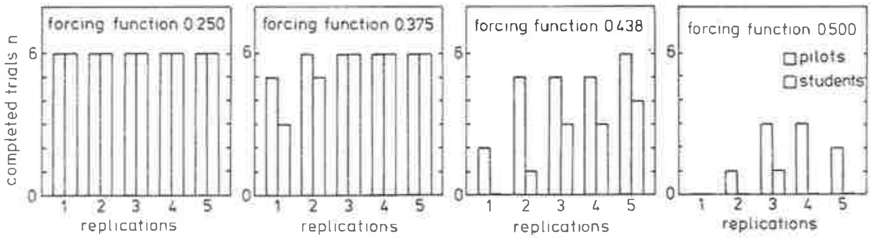


Fig. 3.6 The number of completed trials as a function of pilots and students, forcing functions and replications, summed over subjects. The maximum number of n amounts to 6 per group and per replication on each forcing function.

**Tracking performance; RMS-error (5th replication)**

The results of ANOVA are summarized in Table 3.1.

Table 3.1 Summary of the ANOVA concerning RMS-error (5th replication).

| SOURCE | F | df | p |
|---|---|---|---|
| Groups (GR) | 6.1 | 1,10 | <.05 |
| Subjects within GR (Ss w. GR) | | 10 | |
| Forcing functions (FF) | 2.8 | 2,20 | n.s. |
| GR x FF | 4.9 | 2,20 | <.05 |
| (Ss w. GR) x FF | | 20 | |

The ANOVA showed a significant main effect between groups and a significant interaction between groups and forcing functions. As shown in Fig. 3.7 this interaction is caused by relatively large tracking error of students at FFI 0.438. Post-hoc Newman-Keuls analysis revealed that the students' score at FFI 0.438 significantly differed from the other scores ($p < .05$). There were no other significant effects.

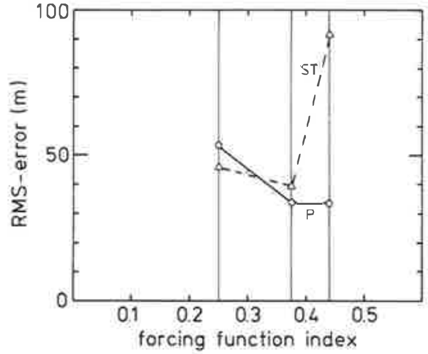


Fig. 3.7 RMS-error as a function of groups (STudents, Pilots) and forcing functions, averaged over subjects.

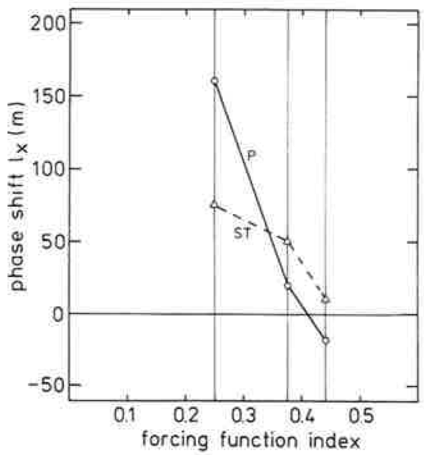


Fig. 3.8 Phase-shift $l_x$ as a function of groups (STudents, Pilots) and forcing functions, averaged over subjects.

**Tracking performance; phase-shift $l_x$ (5th replication)**

The results of the ANOVA only showed a significant main effect between forcing functions ($F = 8.6$; $df = 2,20$; $p < .01$). Fig. 3.8 shows that the ship's path has an average phase-lead of approximately 100 m at FFI 0.250. This lead decreases as a function of increasing forcing function index. There were no other significant effects.

**Tracking performance; amplitude-ratio $\alpha$ (5th replication)**

The results of the ANOVA only showed a significant main effect between forcing functions ($F = 3.6$; $df = 2,20$; $p < .05$) (see Fig. 3.9). The absolute magnitude of the amplitude deviations can be neglected in comparison with the values of the other performance indicators. There were no other significant effects.

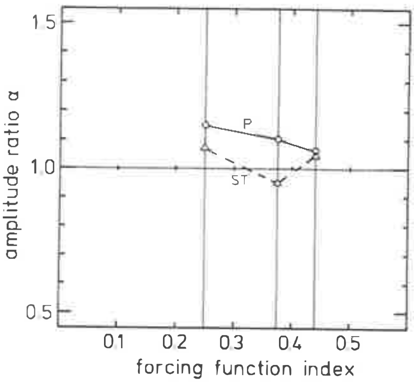


Fig. 3.9 Amplitude-ratio $\alpha$ as a function of groups (STudents, Pilots) and forcing functions, averaged over subjects.

**Tracking performance; SD Rudder deflection $\sigma_\delta$ (5th replication)**

The results of the ANOVA only showed a significant main effect between forcing functions ($F = 195.0$; $df = 2,20$; $p \ll .01$). Post-hoc Newman-Keuls test showed significant differences ($p < .01$) between individual forcing functions. As was expected, the deviation increased with increasing forcing function index (see Fig. 3.10). There were no other significant effects.

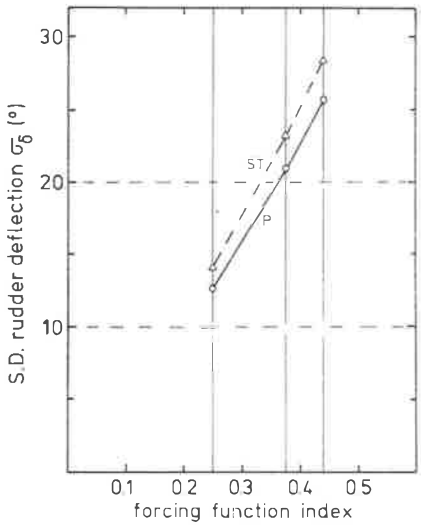


Fig. 3.10 Standard deviation of the rudder deflection $\sigma_\delta$ as a function of groups (STudents, Pilots) and forcing functions, averaged over subjects.

### 3.2.4 Discussion

**Summary of the results**

Summed over all conditions, pilots showed higher n-scores than students ($U = 5$; $p < .05$). There was a significant practice effect of n ($\chi^2_r = 14.2$; $df = 4$; $p < .01$). Students significantly improved their performance as a function of replications at FFI 0.375 ($Q = 9.7$; $df = 4$; $p < .05$).

Tracking performance indicators showed that the travelled path phase-lead decreased as a function of increased forcing function index ($F = 8.6$; $df = 2,20$; $p < .01$). The amplitude-ratio differed significantly between forcing functions. The RMS-error amounted to 40 m for pilots and to 59 m for students ($F = 6.1$; $df = 1,10$; $p < .05$), particularly due to differences at FFI 0.438 ($F = 4.9$; $df = 2,20$; $p < .05$) at which pilots showed a RMS-error of 34 m and students of 95 m.

The standard deviation of the rudder deflection increased with an increasing index of the forcing function ($F = 195.0$; $df = 2,20$; $p \ll .01$).

**Slow and rapid tasks**

As expected, there were differences in performance between forcing functions with low and high index. Dike collisions seldom occurred in forcing functions with a low index when only small rudder deflections were required. As indicated by the n-scores, adequate performance was already observed in the first trial at FFI 0.250 for pilots as well as for students. This shows that both groups could effectively use feedback control in manoeuvring the vessel. Pilots' performance at FFI 0.375 was approximately adequate while students also showed adequate performance after practice. At FFI 0.438 both groups tended to reach adequate performance but practice effects were not significant. At FFI 0.500 adequate performance was seldomly reached and no practice effects were found. This shows that both groups had neither an accurate motor memory nor did they develop one.

In **rapid** tasks (FFI 0.500) the inadequate performance of pilots was not expected. Performance seems to level off (n-scores) which suggests an inaccurate motor memory. With regard to practical conditions, this result could be of considerable importance. Generally, pilots handle all types of ships without intensive ship-specific training. After their boarding, there is rarely time for familiarization with the ship dynamics. Obviously pilots may not have a general motor memory available that allows accurate performance at specific conditions.

The results with regard to **slow** tasks support the idea that adequate performance at FFI 0.250 and FFI 0.375 is particularly due to a perceptual memory since motor memory is not adequate. For the same reason it is suggested that performance at FFI 0.438 is seriously more degraded than at FFI 0.250 and FFI 0.375 since a motor memory is supposed to be an important factor at that function. As expected, pilots performed significantly better than students at FFI 0.438. The significant difference shown by the RMS-error at FF 0.438 between pilots and students parallels the expectation to the extent that pilots have available a "less inaccurate" motor memory than students. The amplitude-ratio and the phase-shift do not differ between groups. This suggests that track references are more or less the same in both groups, hence a "less inaccurate" motor memory could indeed have produced a smaller tracking error as shown by the RMS-error.

It could be argued that the manoeuvring conditions were quite unusual. Pilots do not practise this type of task. The experimental results show that the rudder deflection standard deviation amounts to 13° at FFI 0.250, 22° at FFI 0.376, and 27° at FFI 0.438. The performance at FFI 0.250 is hence just beyond the limit of normal control condition and the manoeuvre at FFI 0.376 can be approximately characterized as an emergency manoeuvre. At FFI 0.250 pilots could keep the vessel on track within an accuracy of 40 m (RMS-error) which seems to be reasonable (Sukselainen, 1975). Hence, the FFI 0.250 represents approximately a normal manoeuvring condition, and FFI 0.376 an extreme manoeuvre.

Summarizing the practice effects so far, adequate performance was observed at FFI 0.250 for both groups on the first trials. Students showed practice effects and tend to reach adequate performance level. This level was not achieved entirely by the students at FFI 0.438 and in particular by neither group at FFI 0.500. The results suggest an effective use of feedback. Motor memory is not accurate.

## 3.3 Experiment 2: Performance of pilots as a function of radar and view

### 3.3.1 Introduction

In this experiment Wylie's (1976) suggestion that experienced mariners primarily perform ship manoeuvres by feedback was tested. To approximate system performance in real-life conditions as closely as possible, experienced pilots were asked to track various forcing functions with a 40,000 ton container vessel. The forcing functions were visible through the bridge windows, or on a radar display or both. In comparison to Experiment 1, the number of forcing functions was extended with functions with low indexes to include normal manoeuvring conditions. Moreover, since pilots most often have no opportunity on board for familiarization with the ship dynamics, it was necessary to have pilots without intensive, ship-specific training and without practice on the completion of forcing function. Hence, experienced pilots were only familiarized with the simulator and they completed each forcing function only once in order to determine their tracking ability as if they had just boarded the vessel.

In **slow** tasks, where performance is supposed to depend mainly on perceptual memory, feedback on the ship's position and position change plays a major role. When sufficient preview is provided (Poulton, 1974), accurate performance mainly depends on the perception of the change of status immediately after the control setting (Concklin, 1957). Subjects can extrapolate the outcomes and evaluate these outcomes with regard to a correctness reference. Stimuli constituting the preview will probably differ between view and radar conditions and therefore will affect performance. As will be detailed in section 4.2, it is expected that view degrades preview due to less accurate perception of distance to a target at long range. Since preview length is assumed to be limited within approximately 5 ship's lengths this effect could be of minor importance. In the present experiment pilots were only instructed and not trained on the correct track, hence it is assumed that in all presentation modes the perceptual memory is not developed accurately. It is expected therefore, that in a view condition performance will be fairly accurate, although the effects of control actions are instantaneously presented. In a radar condition, it is expected that feedback is degraded by degraded presentation of position changes at low (turning) rates which will deteriorate performance accuracy. Radar in a combined View/Radar condition will not contribute to improvement of performance with regard to a View condition since performance is assumed to depend mainly on feedback.

In a **rapid** task, the motor memory hypothesis predicts an equivalent performance in view and radar conditions, because feedback can play no role while the necessary preview is assumed to be adequately presented by Radar as well as by View. The results of Experiment 1, however, suggest that pilots do not have available a proper motor memory. Hence performance in rapid tasks will be inadequate and independent of presentation mode. Also at forcing functions with high indexes performance will be inadequate because of the supposed dependency on perceptual **and**, to a certain extent, motor memory.

### 3.3.2 Method

**Subjects**

Eighteen subjects, retired pilots of 55-58 years of age, took part in the experiment. They had ample experience in conning of all types of vessels. All subjects had a normal or corrected to normal vision.

**Task**

The subjects were asked to conn a 40,000 ton container vessel (see Appendix I) as accurately as possible along seven different forcing functions. The ship travelled at a constant initial forward speed of approximately 19 knots. The forcing functions were visible through the windows of a bridge mock-up (View), on a radar display (Radar), or both (View/Radar).

**Experimental design**

Two variables were combined factorially. Presentation (PR, 3 levels) was varied between subjects and forcing functions (FF, 7 levels) was varied within subjects. The 18 subjects were divided into three groups of six subjects each. Each group was assigned to one of the three presentation levels (View, Radar, View/Radar). Testing order was balanced.

As in the previous experiment, forcing function index was defined by the ratio of the double amplitude (333 m) and half period length (l) (FFI = 0.125; 0.191; 0.250; 0.312; 0.375; 0.438; 0.500).

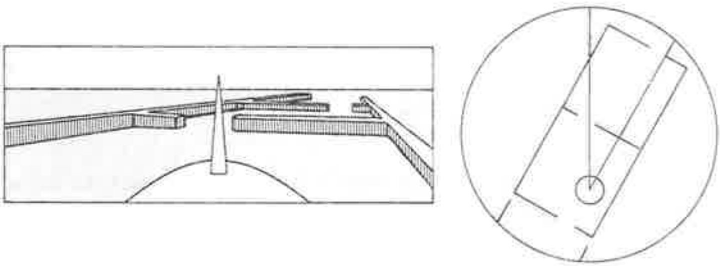

Fig. 3.11 Definition of a zig-zag track by means of outside view or radar presentation (at right). On the radar display a heading-line (ship's centre line) and a bearing-marker (parallel to the forcing function axis) were visible.

The View and Radar conditions are illustrated in Fig. 3.11. The radar display showed a relative motion, head-up picture with an off-centre adjustment of 60%.

**Training and instruction**

The subjects were familiarized with the forcing functions by means of a practice trial with two irregular forcing functions. Thereafter the subjects completed all seven forcing functions.

The subjects were asked to follow a sine-wave track by passing the centre of the openings with a heading parallel to the fairway-axis. The ship's path between the openings should be as smooth as possible. Large rudder deflections were to be avoided. These instructions provided the conditions designed to produce a sine-wave track.

**Procedure**

Each subject took part in the experiment for one day. After familiarization and instruction, seven forcing functions were completed. Each trial took about 25 min. There was a rest of 5 min between successive runs. The bridge mock-up was only left during a half-hour lunch-break.

In contrast to the previous experiment, a run was continued after a collision with a dike.

**Scoring and analysis**

**Completed trials** In contrast to the previous experiment, trials were not stopped; all trials were completed.

**Tracking performance** The deviations between the forcing function and the actually travelled path were indicated by the root-mean-squared error (RMS), by the phase-shift of forcing function and travelled path ($l_x$) and by the gain ratio of both curves ($\alpha$).

RMS-error: the root-mean-squared error as index for tracking error as described in Experiment 1

$l_x$ and $\alpha$ : as indices for phase-shift and for amplitude-ratio of the ship's path relative to the forcing function as described in Experiment 1

$\sigma_\delta$ : the standard deviation of the rudder deflection as index for the extent the inherent controllability was approximated.

The scores were subjected to ANOVA with PR (3 levels), Subjects (6 levels), and FF (7 levels) as variables.

### 3.3.3 **Results**

**Tracking performance; RMS-error**

The results of the ANOVA are summarized in Table 3.2.

Table 3.2 Summary of the ANOVA concerning RMS-error.

| SOURCE | F | df | p |
|---|---|---|---|
| Presentation (PR) | 13.0 | 2,15 | << .01 |
| Subjects within PR (Ss w. PR) | | 15 | |
| Forcing functions (FF) | 27.2 | 6,90 | << .01 |
| PR x FF | 1.9 | 12,90 | = .05 |
| (Ss w. PR) x FF | | 90 | |

The ANOVA showed that RMS-error was significantly larger in the Radar-condition (100 m) than in the other presentation conditions (View = 63 m; View/Radar = 69 m). Post-hoc Newman-Keuls test showed significant differences of R versus VR and V (p < .01). The main effect of forcing functions was highly significant. Newman-Keuls test showed significant differences of FFI = 0.500 and FFI = 0.438 versus

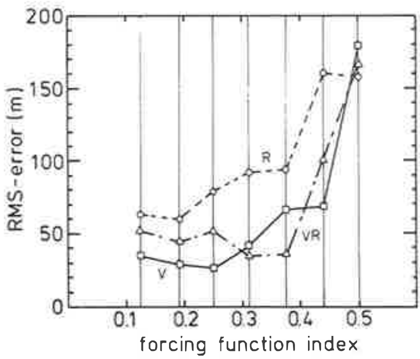


Fig. 3.12 The RMS-error as a function of presentation and forcing function, averaged over subjects.

the other FFIs. The interaction presentation x forcing functions ($p = .05$) showed a strong increase of RMS-error in the Radar-condition at the FFI 0.438 (see Fig. 3.12). Post-hoc Newman-Keuls test showed significant differences at FFI 0.438 between R-V ($p < .01$) and R-VR ($p < .05$).

**Tracking performance; phase-shift $l_x$**

The results of the ANOVA are summarized in Table 3.3.

Table 3.3 Summary of the ANOVA concerning $l_x$.

| SOURCE | F | df | p |
|---|---|---|---|
| Presentation (PR) | 2.4 | 2,15 | n.s. |
| Subjects within PR (SS w. PR) | | 15 | |
| Forcing functions (FF) | 59.8 | 6,90 | << .01 |
| PR x FF | 2.1 | 12,90 | < .05 |
| (Ss w. PR) x FF | | 90 | |

The ANOVA showed a highly significant forcing function effect. Post-hoc Newman-Keuls test showed significant differences between all FFIs, except the FFIs 0.125 versus 0.191, 0.125 versus 0.250, 0.191 versus 0.250 and 0.312 versus 0.375. The phase-lead changes as a function of increasing FFI into a phase-lag for all three PR-conditions.

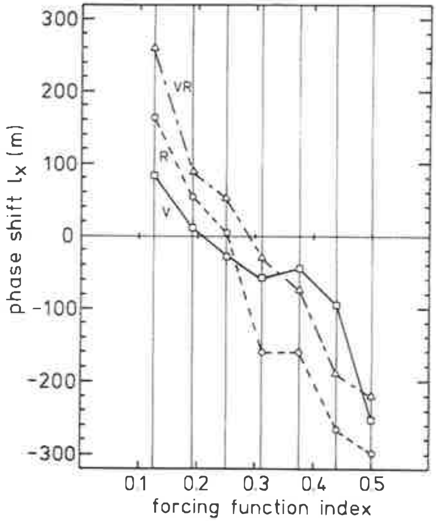


Fig. 3.13 Phase-shift $l_x$ as a function of presentation and forcing function, averaged over subjects.

The interaction between presentation and forcing function, illustrated in Fig. 3.13, showed small leads and lags in the View-condition. Post-hoc Newman-Keuls tests showed only significant differences at FFI 0.438 between R-V ($p < .01$) and R-VR ($p < .05$).

**Tracking performance; amplitude-ratio $\alpha$**

The results of the ANOVA are summarized in Table 3.4.

Table 3.4 Summary of the ANOVA concerning $\alpha$.

| SOURCE | F | df | p |
|---|---|---|---|
| Presentation (PR) | 1.9 | 2,15 | n.s. |
| Subjects within PR (Ss w. PR) | | 15 | |
| Forcing functions (FF) | 2.9 | 6,90 | < .05 |
| PR x FF | 4.0 | 12,90 | << .01 |
| (Ss w. PR) x FF | | 90 | |

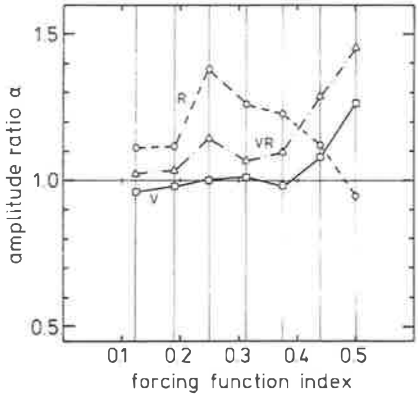


Fig. 3.14 Amplitude-ratio α as a function of presentation and forcing function, averaged over subjects.

The ANOVA showed a non-significant main effect of presentation and a significant increase in the α with increasing FFI. The significant interaction between presentation and forcing functions in the Radar-condition is due to a decrease in α at FFIs larger than 0.250 in contrast to a continuous increase in α in the View/Radar and View-condition (see Fig. 3.14). A post-hoc Newman-Keuls test showed a significant difference at FFI 0.250 between R-V ($p < .05$) and at FFI 0.500 between R-VR ($p < .01$).

**Tracking performance; SD Rudder deflection $\sigma_\delta$**

The results of the ANOVA are summarized in Table 3.5.

Table 3.5 Summary of the ANOVA concerning $\sigma_\delta$.

| SOURCE | F | df | p |
|---|---|---|---|
| Presentation (PR) | 6.1 | 2,15 | < .05 |
| Subjects within PR (Ss w. PR) | | 15 | |
| Forcing functions (FF) | 435.0 | 6,90 | << .01 |
| PR x FF | 7.4 | 12,90 | << .01 |
| (Ss w. PR) x FF | | 90 | |

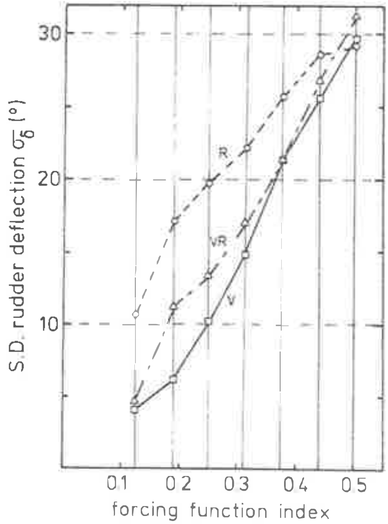


Fig. 3.15 The standard deviation of the rudder deflection $\sigma_\delta$ as a function of presentation and forcing function, averaged over subjects.

The ANOVA showed a larger standard deviation of the rudder deflection in the Radar-condition than in both other presentation conditions. Post-hoc Newman-Keuls test showed significant differences of R versus V and VR ($p < .05$). There was a highly significant forcing function effect. All indexes differed significantly (Newman-Keuls test, $p < .01$). The maximal rudder deflection is approximately met in all three presentation conditions at FFI 0.500 (see Fig. 3.15). The interaction between presentation and forcing functions was significant. A post-hoc Newman-Keuls test showed significant differences between R-VR ($p < .01$) and R-V ($p < .01$) at all FFIs, except FFI 0.125 and FFI 0.500. At FFI 0.500 R-VR ($p < .01$) and V-VR ($p < .05$) significantly differed.

### 3.3.4 Discussion

**Summary of results**

The results showed significant differences between performance in conditions with View versus conditions with Radar. Slow tasks were performed fairly accurate in conditions with View, the rapid task was inaccurately performed in all presentation conditions.

The RMS-error in the View and View/Radar-condition approximated 65 m while this error amounted to 100 m in the Radar-condition. As expected, the RMS-error increased with increasing forcing function index ($F = 1.9$; $df = 12,90$; $p = .05$). Also the amplitude-ratio showed low values at slow tasks in the View and View/Radar-condition in contrast with the Radar-condition ($F = 4.0$; $df = 12,90$; $p \ll .01$). The $l_x$ showed significant differences between the various forcing function indexes. The average phase-shift at FFI 0.125 amounted to 160 m lead and amounted at FFI 0.500 to 250 m lag ($F = 5.98$; $df = 6,90$; $p \ll .01$). The phase-shift differed between presentation conditions at FFI 0.438 only.

The standard deviation of the rudder deflection in the View and View/Radar-condition was smaller than in the Radar-condition ($F = 6.1$; $df = 2,15$; $p < .05$). At FF 0.500 the maximal deviation was approximated in all presentation modes ($F = 7.4$; $df = 12,90$; $p \ll .01$).

**Pilot's performance in slow tasks**

The forcing functions with indexes lower than 0.250 may be categorized on the basis of the rudder deflection standard deviation as normal manoeuvres for the View and View/Radar-condition. As was expected, performance in the View-condition was fairly accurate.

The results confirm the expectation that feedback determines performance to a large extent. One should recall that in all presentation modes subjects had visual information about both a part of the fairway and about their own position. This permits the kind of anticipation referred to as receptor anticipation (Poulton, 1957). In contrast to the View-condition, the Radar-condition could degrade feedback and hence, could introduce poor anticipation of the ship's future position. Poor anticipation leads to uncertainty in giving rudder calls (Poulton, 1952) as is shown in Fig. 3.15 and introduces inaccurate performance as indicated by the tracking performance indicators.

As expected, Radar in a Radar/View-condition does not improve performance relative to a View-condition. Hence, possible degradation of preview in the View-condition is indeed a less important factor.

Some deviations in $l_x$ and $\alpha$ between View and View/Radar (although not significant) are of interest. It was not expected that Radar in a View/Radar-condition would introduce a negative effect on performance. It is argued that in a View/Radar-condition View mediates the most important feedback. The less adequate performance in the combined View/Radar-condition could be due therefore, to interference between View and Radar as Radar cannot sufficiently mediate feedback. Hence, Radar in a View/Radar-condition urges the subject to allocate his attention to both information sources while it does not add substantially new information.

**Pilot's performance in rapid tasks**

The accuracy of performance decreases as a function of increasing forcing function index. The rapid task, presented by FFI 0.500, is performed inadequately in all three presentation conditions and these results confirm those of Experiment 1 that pilot's behaviour is not based on an accurate motor memory. RMS, $l_x$ and $\alpha$ show performance degradation at functions with high indexes. Hence, the more a motor memory is needed, the less accurate performance becomes. It can be concluded that experienced pilots have an inaccurate motor memory.

The use of feedback in a rapid task and at forcing functions with high indexes is indicated by the inaccurate performance ($l_x$, RMS) in the Radar-condition relative to View- and View/Radar-condition.

The amplitude-ratio in the Radar-condition decreases with increasing indexes which is in contrast to the other presentation modes. As can be inferred from the standard deviation of the rudder deflection the performance in the Radar-condition at FFI 0.250 approximates emergency manoeuvring. This suggests that control transgresses the limits of the pilots' ability which urges the subjects to violate the instructions by accepting lower amplitude-ratios.

**Standard deviations of the rudder deflection**

The values of the standard deviations of the rudder deflection in the View-condition are approximately equal to the values found in Experiment 1. As was expected, normal manoeuvring conditions are presented by forcing functions with an index of less than 0.250 and emergency condition by forcing functions with an index of 0.250 and 0.375.

## 3.4 Summary

In this chapter the ship tracking task was simplified to a laboratory tracking task in order to investigate the components of the ship handler's ability to control a vessel. The laboratory tracking task required the operator to track an intended route precisely.

The intended routes were defined by ships' paths, resulting from zig-zag manoeuvring tests. These paths were marked by dike openings in fairways (forcing functions). These forcing functions represented one rapid and various slow (manoeuvring) tasks. The rapid task could only be completed on the basis of a motor memory component while the slow tasks could also be based on a perceptual memory component.

Two tracking experiments were discussed. In the first experiment, pilots and students completed tracking tasks with a 40,000 ton container vessel to check the expectation whether experienced subjects have a motor memory available. In the second experiment this expectation was further tested, in particular with regard to view and radar as means for presenting fairway and ship movements. Results support Wylie's (1976) suggestion that mariners primarily perform their tracking task on the basis of feedback. Neither pilots nor students have an accurate motor memory. In addition, it was established that normal manoeuvring conditions are represented by forcing function indexes lower than 0.250. Index 0.375 represents an emergency condition.

Mariners seem to be involved exclusively in the performance of slow tasks. In the performance of these slow tasks a motor memory, although inaccurate, is probably of partial importance. Presumably, manoeuvres, represented by forcing functions with low indexes, can be performed accurately on the basis of feedback only, while accurate performance on forcing functions with high indexes need to some extent a motor memory component.

# 4 RESPONSE SELECTION IN APPROACHING A DESIRED POSITION

## 4.1 General

As argued in Chapter 2, operators use information from their past experience when controlling variables of slow responding processes. The information from initial conditions, desired and past outcomes, and feedback is stored in memory and becomes an essential element in the operator's ability to perform control tasks accurately. It allows prediction of the effects of response selection (control setting) which enables the operator to anticipate future process states and to minimize control errors caused by the slow response of the process under control.

The memory mechanisms involved in this control behaviour are supposed to consist of two compensatory elements: a motor memory and a perceptual memory. In this chapter the role of motor memory in the generation of responses is studied.

Briefly summarizing the argument in Chapter 2, motor memory refers to the open-loop characteristic of both the internal model concept and the recall schema. Two alternative hypotheses were formulated:

A **motor memory** conceived of as a **memory trace** assumes a rough relation between initial conditions, desired outcomes, past outcomes and rudder deflections. This hypothesis belongs to Adams' closed-loop theory (1971). Adams' memory trace is merely a component in the adjustment of direction and the initiation of actions and not in the control of the process outcomes as a result of actions. Such a rough **motor memory** is therefore only useful when performing slow tasks (see Chapter 3), because in that case behaviour is based mainly on feedback control compensating for the inaccurate functioning of such a motor memory.

Again, a **motor memory** conceived of as a **recall memory** or an internal model assumes an accurate relationship between initial conditions, desired outcomes, past outcomes and rudder deflections. This hypothesis follows from Schmidt's schema theory (1975) and the internal model notion. An accurate **motor memory** is developed on the basis of extensive practice. The accurate motor memory can be characterized as an accurate behavioural component for adjusting control effects without involvement from extero-and proprioceptive feedback and is particularly relevant when performing rapid tasks.

The essence of the internal model notion can be understood as a motor memory to the extent that it consists of a representation of the process dynamics (Wickens, 1983), enabling the operator to select the appropriate control setting on the basis of predicted and desired outcomes. The internal model can be characterized as an accurate memory for generating response specifications applicable to rapid tasks. The internal model resembles the recall memory as far as the relation of initial conditions, desired outcomes, response specifications and past outcomes are concerned.

The contributions of motor memory to the accuracy of tracking performance will be analysed by studying the accuracy of selecting a single rudder deflection as a control setting to approach a desired position. The requirement of selecting a single control setting resembles that part of the task that is based on motor memory. Development of accurate selection of rudder deflection as a function of practice would be in line with the accurate motor memory hypothesis and hence with Schmidt's recall schema and the internal model notion. Continuing inaccurate selection as a function of practice would be consistent with the rough motor memory hypothesis and hence in line with the memory-trace hypothesis of Adams (1971).

It was demonstrated in Chapter 3 that the mode of fairway presentation affects performance. When approaching a desired position, it is obvious that stimuli for the subject's response specification will differ between View and Radar. As will be detailed in section 4.2, it is expected that distance estimation to positions at long range with Radar will be superior to View and will enhance accuracy of selection.

In section 4.2 an experiment is discussed concerning the selection accuracy of a rudder deflection to approach a desired position, while in section 4.3 an experiment is discussed on the effects of KR on the selection accuracy.

## 4.2 Experiment 3: The selection accuracy of a rudder deflection

### 4.2.1 Introduction

A simple control task was designed to test the hypothesis that the selection of a single rudder deflection in approaching a desired position can be accurate since it is based on an accurate motor memory as predicted by the internal model notion as well as by the schema theory (Schmidt, 1975).

A ship travels at a constant initial forward speed on a straight course. The subject is asked to steer the ship to a desired position by selecting **one** of a range of available rudder deflections at a predetermined location (see Fig. 4.1).

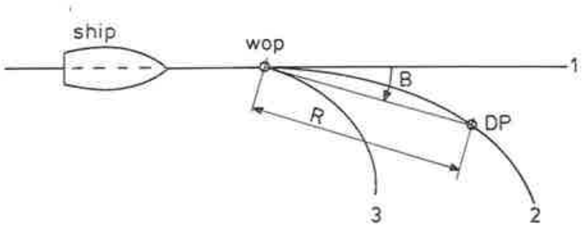


Fig. 4.1 At the wheel-over-point (WOP) a rudder deflection between 0° (path 1) and maximally 35° (path 3) has to be selected. The selection should result in a path (2) that crosses the desired position (DP). This position is defined by Range (R) and Bearing (B).

The desired position is shown by one out of two presentation modes: a simulated radar picture (Radar) or a simulated view through the bridge windows (View).

An accurate motor memory assumes that a subject will select a rudder deflection on the basis of initial conditions, desired outcomes and past outcomes. In this experiment the initial conditions can be neglected because they are constant and without disturbances. The hypothesis predicts that subjects learn how to improve the accuracy of selection by using the distance between desired position (desired outcome) and the effectuated position (past outcome) as knowledge of results. Salmoni et al. (1984) call this the guidance role of KR.

Schmidt (1975) has suggested that each response specification produces a memory parameter to relate response (control setting) and outcome. With repeated responses using different parameter values and producing different outcomes, a subject develops a rule between the parameter that produces the outcome and the desired outcome. After practice this constitutes the recall schema in Schmidt's theory.

Concerning the development of an internal model Kelley (1968) argued that "... (subject) begins (the) operation with some kind of internal model of his system, which he employs to make predictions. The predictions he makes often prove in error and force him to change his model. New predictions based on the revised model will usually be better but still in error, permitting additional, usually smaller, changes to be made in the model ..." (Kelley, 1968, p. 80). As experience is gained, the model is adjusted to further reduce errors in predictions. When the internal model has been developed, the subject notes the particular desired outcome. The internal model, established by past experience, provides a control setting that will come closest to accomplishing the particular desired process outcome.

During early learning, inaccurate control settings are to be expected because in this presumably cognitive (Fitts, 1964; Fitts & Posner, 1967) or verbal-motor phase (Adams, 1971) the learner attempts various different ways of solving the selection problem. When knowledge of results (KR) is provided the performance will strongly improve during this phase. In this phase improvement is supposed to be larger than at any other single period of learning. In the present experiment subjective reinforcement can substitute KR because the subject can provide KR to him or herself in the same way as the experimenter would do. Since subjects are required to select a single rudder deflection, the task can be viewed as a rapid task since selection of the rudder deflection consists of an aiming movement and completion without error correction. Deviations between desired and effectuated outcomes are objectively presented to the subject and can be readily considered as KR. This favours the development of an accurate motor memory. The outcome reflects the result of a single control setting so as to reveal deviations from desired outcomes. This should represent an ideal condition for developing an accurate motor memory.

The presentation is likely to affect the accuracy of rudder selection. It is assumed that both in Radar and View-conditions the various desired positions are perceived as distinct as soon as the Weber fraction of the corresponding visual angle between desired positions and relevant references is exceeded.

In the Radar-condition the relevant references are the ship's heading line, the observer's position, the range and bearing of the desired position and possibly also the edges of the display.

In the View-condition other factors are likely to play a role as well. Ogle (1962) considers object size as the most important factor in estimating distance to an object, but he also mentions the loss of contrast as a function of distance, texture, and object location relative to the horizon. These suggestions parallel the findings of Künnapas (1968).

To distinguish between the size of two simultaneously presented objects, the just noticeable difference amounts to 3% (Ogle, 1962). When, however, the objects are observed one after the other, the Weber fraction will be larger because the second object is internally compared with a memory trace of the first object. The results of Vroon (1972) on the discrimination of successively presented discs with a diameter of 25, 29 and 33 mm at 750 mm observation distance shows fractions of approximately 33%. The results show that the discs of 25 and 33 mm diameter were confused in 1% of all presentations. Hence, when only object size is used for range estimation, there will be a probability of 1% of confusing distances when object sizes differ approximately by a factor of 1.3. This means that for the range estimation of positions, radar will be at an advantage at long range when the viewing angle of objects in the View-condition will approximate the perceptual threshold due to perspective presentation. The estimation of bearings will not be affected by view and radar when the Weber fraction differs by about 30% or more between positions in the eye field of the observer.

### 4.2.2 Method

#### Subjects

Six male and six female University students took part in the experiment. Their age was between 20-25 years and they had normal or corrected-to-normal vision. They had no experience with ship control.

### Task

The ship travelled at an initial constant forward speed of approximately 19 knots on a straight course. The desired position was marked by the symbol of a buoy. At a predetermined range and bearing from the desired position, the subject was forced to select a single rudder deflection so as to cause collision between the desired position and the stem of the vessel. After the selection the subject watched the effects of the rudder deflection on the vessel's position and heading. The correctness of the selected deflection was evident from the extent that stem and buoy symbol coincided.

There were twelve desired positions by combining four ranges (750, 1000, 1250, 1500 m) and three bearings (7.5, 15.0, 22.5°). The desired positions were visible through the windows of the bridge mock-up (View) or on a radar display (Radar).

A small test was conducted to check the assumption that the desired positions can be discriminated in the Radar-condition when at least range or bearing of two adjacent positions by differed approximately 30%. Results show that the assumption is valid (see the Appendix at the end of this section on page 80).

### Experimental design

Five factors were combined in the experimental design. The factor Presentation (PR, 2 levels) was varied between subjects to avoid asymmetrical transfer between View and Radar-conditions. The factors Range (R, 4 levels), Bearing (B, 3 levels) and Replications (RE, 8 levels) were varied within subjects. Twelve subjects were divided into two groups of six subjects. Each of which was allocated to one Presentation-condition. Testing order was balanced.

### Instrumentation

A subject was seated on a chair at the centre window of the bridge mock-up of the simulator and had a keyboard for typing the rudder deflection in integers between 0 and 35. The selected rudder deflection was displayed just above the keyboard.

In the View-condition the desired position was indicated by a pole of 17 m height, with a 17 m long horizontal pole as a basis (see Fig. 4.2). Horizon, air, sea-surface and foredeck with mast were also visible. The observer's position was 25 m above the sea surface. In the Radar-condition the desired position was presented by a cross-wire of 1 x 1 cm on a radar display. On this display with a scale of

1:10,000, the observer's position, the ship's stem and the heading line were also depicted. The ship's position was fixed at the bottom of the display in a head up orientation, the buoy symbol moved (see Fig. 4.3). The refresh rate of the radar picture amounted to 24 pictures per minute.

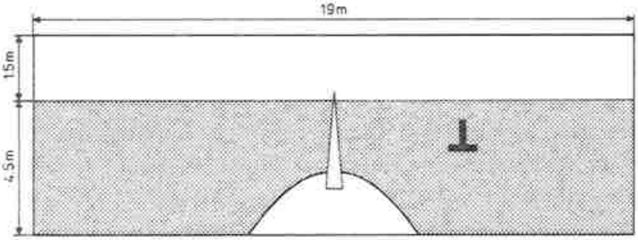


Fig. 4.2 The View-condition shows a perspective view on the foredeck and surrounding. The picture is presented on a large screen at 9 m distance from the observer (see the Appendix).

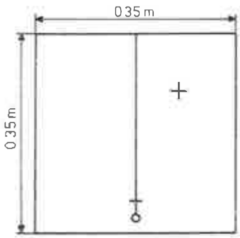


Fig. 4.3 The Radar-condition with a fixed heading line and indications of the stem and the observer's position. The desired position, indicated by a cross-wire, moves. The picture is presented on a CRT at 0.60 m distance from the observer.

**Instruction and training**

The subjects were informed about the effects of rudder deflections on the ship's position and heading. They were told that in order to approach a position at short range and large bearing large rudder deflections were needed. For approaches to positions at large distance and small bearing small deflections should be selected. The subjects were to watch the ship's position and heading change after the rudder deflection and the deviation ultimately achieved between desired and effectuated position. This information was to be used for improving the accuracy of rudder selection in following trials.

The subjects did not receive advance practice except for one demonstration trial with a desired position which did not belong to the experimental conditions.

**Procedure**

Each subject was tested on 8 successive replications of 12 trials each. Between replications there was a short rest. In the Radar-condition the subjects were tested between 9.00 - 13.00 or 13.30 -17.30. In the View-condition the subjects were tested between 9.00 - 16.00 because of the time needed for restarting the simulator between trials.

After the start of each trial it took 30 s before the wheel-over-point was reached. At that location the trial was interrupted and continued after the selection of a rudder deflection. Each run was ended when an imaginary line between stem and desired position became perpendicular to the ship's centre line.

**Scoring and analyses**

$\delta_r$: the relative rudder deflection. The selected rudder deflection ($\delta$) divided by the desired rudder deflection ($\delta_d$) as a measure for indicating a systematic deviation from the desired rudder deflection.

$V_{\delta r}$: the variability of the relative rudder deflection. The standard deviation of the relative rudder deflection was calculated for the first and the second half of the eight replications as a measure for indicating the variability of the selection of rudder deflections.

The desired rudder deflections for reaching the various desired positions are shown in Table 4.1.

Table 4.1 The desired rudder deflection $\delta_d$ (°) as a function of range and bearing of the desired position relative to the ship's position and heading at the wheel-over-point.

| | Bearing ° | | |
|---|---|---|---|
| | 7.5 | 15.0 | 22.5 |
| Range m | | | |
| 1500 | 2 | 4 | 6 |
| 1250 | 3 | 6 | 8 |
| 1000 | 4 | 9 | 13 |
| 750 | 8 | 16 | 26 |

The scores were subjected to an analysis of variance (ANOVA).

The $\delta_r$ was analysed for PR (2 levels), Subjects (6 levels), R (4 levels), B (3 levels) and RE (8 levels).

The $V_{\delta r}$ was calculated for the first and second half of the eight replications and was analysed for PR (2 levels), Subjects (6 levels), R (4 levels), B (2 levels) and RE (2 levels).

### 4.2.3 Results

**The relative rudder deflection; $\delta_r$**

Results of an ANOVA are summarized in Table 4.2.

Table 4.2 Summary of an ANOVA concerning $\delta_r$.

| Source | F | df | p | Subject | F | df | p |
|---|---|---|---|---|---|---|---|
| PResentation (PR) | 15.2 | 1,10 | <0.01 | PRxRE | 0.3 | 7,70 | n.s. |
| Subjects within PR | | 10 | | (Ss w. PR)xRE | | 70 | |
| Range (R) | 83.1 | 3,30 | <<0.01 | RxRE | 0.7 | 21,210 | n.s. |
| PRxR | 0.9 | 3,30 | n.s. | PRxRxRE | 0.8 | 21,210 | n.s. |
| (Ss w. PR)xR | | 30 | | (Ss w. PR)xRxRE | | 210 | |
| Bearing (B) | 23.6 | 2,20 | <<0.01 | BxRE | 1.7 | 14,140 | 0.05 |
| PRxB | 4.5 | 2,20 | <0.05 | PRxBxRE | 0.9 | 14,140 | n.s. |
| (Ss w. PR)xB | | 20 | | (Ss w. PR)xBxRE | | 140 | |
| RxB | 10.3 | 6,60 | <<0.01 | RxBxRE | 1.1 | 42,420 | n.s. |
| PRxRxB | 1.1 | 6,60 | n.s. | PRxRxBxRE | 1.3 | 42,420 | n.s. |
| (Ss w. PR)xRxB | | 60 | | (Ss w. PR)xRxBxRE | | 420 | |
| Replications (RE) | 2.3 | 7,70 | <0.05 | | | | |

The factor Presentation showed a significant effect, the mean relative rudder deflection amounting to 1.06 in the View-condition and to .88 in the Radar-condition. The factor Range was significant, showing low values of the relative rudder deflections adjusted for positions at short range and high values for positions at long range. The average values of the four ranges differed significantly from each other ($p < .01$) (Newman-Keuls test). This effect was independent of Presentation and Replications (see Figs. 4.4 and 4.6). The factor Bearing was also significant and showed low values at small bearings and high values at large bearings. The significant interaction between Presentation and Bearing proved to be due to strong deviating scores between the View and Radar-condition at 22.5° bearing ($\delta_r$ = 1,37). Post-hoc Newman-Keuls test only showed a significant difference between the condition View, Bearing 22.5°, and the other conditions ($p < .01$) (see Fig. 4.5). The significant interaction between Range and Bearing showed high values ($\delta_r$ = 1,6) for positions at long range and large bearing and low values ($\delta_r$ = .48) for positions at short range and small bearing.

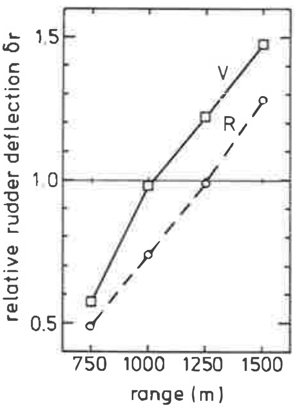


Fig. 4.4 The relative rudder deflection $\delta_r$ as a function of Presentation and Range, averaged over Bearing, Subjects and Replications.

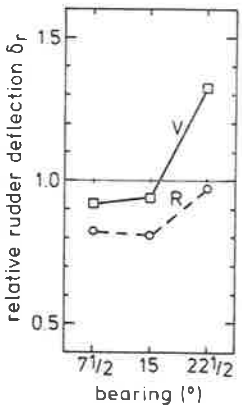


Fig. 4.5 The relative rudder deflection $\delta_r$ as a function of Presentation and Bearing, averaged over Subjects and Replications.

The main effect Replications was significant but failed to express a clear tendency effect of practice. The mean relative rudder deflection fluctuated around $\delta_r = 1.0$. Only the interaction between Bearing and Replications indicated, as a function of Replications, a weak tendency of the relative deflection into the direction of $\delta_r = 1.0$ (see Fig. 4.6 and 4.7).

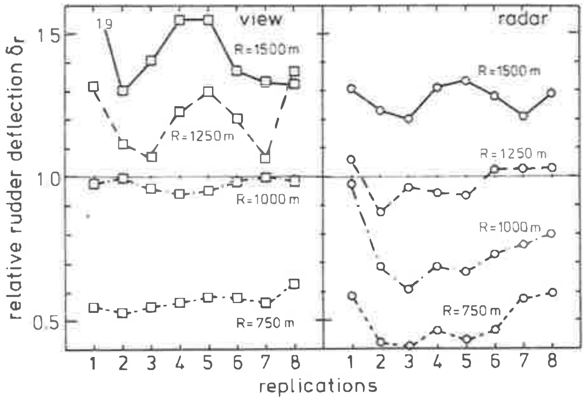


Fig. 4.6 The relative rudder deflection $\delta_r$ as a function of View and Radar, Bearing and Replications, averaged over Bearing and Subjects.

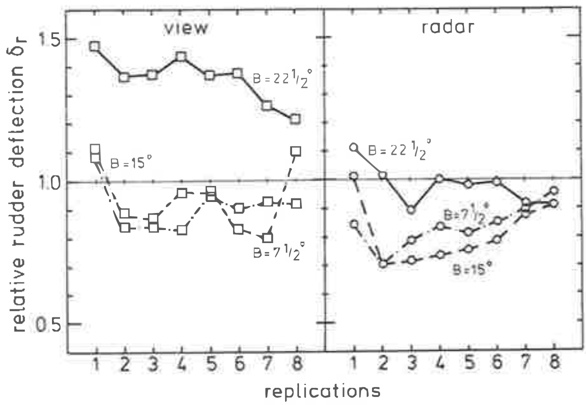


Fig. 4.7 The relative rudder deflection $\delta_r$ as a function of View and Radar, Bearing and Replications, averaged over Range and Subjects.

**The variability of the relative rudder deflection;** $V_{\delta r}$

Results of an ANOVA are summarized in Table 4.3.

Table 4.3 Summary of an ANOVA concerning $V_{\delta r}$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Presentation (PR) | 21.0 | 1,10 | <0.01 | PRxRE | 0.9 | 1,10 | n.s. |
| Subjects within PR | | 10 | | (Ss w. PR)xRE | | 10 | |
| Range (R) | 17.6 | 3,30 | <<0.01 | RxRE | 1.4 | 3,30 | n.s. |
| PRxR | 6.3 | 3,30 | <0.01 | PRxRxRE | 1.1 | 3,30 | n.s. |
| (Ss w. PR)xR | | 30 | | (Ss w. PR)xRxRE | | 30 | |
| Bearing (B) | 1.7 | 2,20 | n.s. | BxRE | 0.2 | 2,20 | n.s. |
| PRxB | 1.4 | 2,20 | n.s. | PRxBxRE | 0.7 | 2,20 | n.s. |
| (Ss w. PR)xB | | 20 | | (Ss w. PR)xBxRE | | 20 | |
| RxB | 0.7 | 6,60 | n.s. | RxBxRE | 0.3 | 6,60 | n.s. |
| PRxRxB | 1.1 | 6,60 | n.s. | PRxRxBxRE | 0.8 | 6,60 | n.s. |
| (Ss w. PR)xRxB | | 60 | | (Ss w. PR)xRxBxRE | | 60 | |
| Replications (RE) | 0.3 | 1,10 | n.s. | | | | |

The factor Presentation was significant, the variability of the relative rudder deflection amounted to .33° in the View-condition and to .19° in the Radar-condition averaged over all conditions. The factor Range showed significant increases in the variability at long range. The significant interaction Presentation x Range is shown in Fig. 4.8. Post-hoc Newman-Keuls test revealed significant differences at R = 1250 m and R = 1500 m between View and Radar ($p < .01$). Within the Radar-condition no significant differences were found. Within the View-condition the average values of the ranges differed, except R = 750 m versus R = 1000 m. The increase in the deviation as a function of Range in the View-condition parallels expectations. The factors Bearing and Replication showed no significant effects (see Fig. 4.9). In contrast with the predictions, there was no practice effect (see Fig. 4.10 and 4.11).

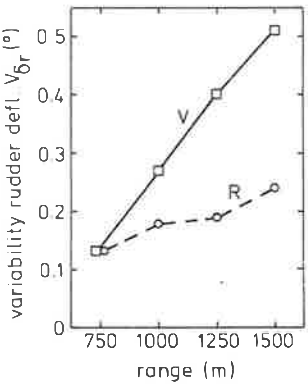


Fig. 4.8 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Range, averaged over Subjects, Bearing and Replications.

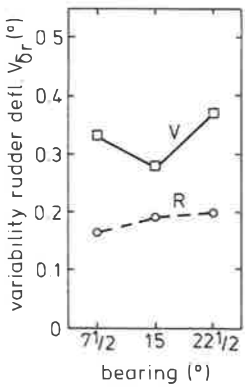


Fig. 4.9 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Bearing, averaged over Subjects, Range and Replications.

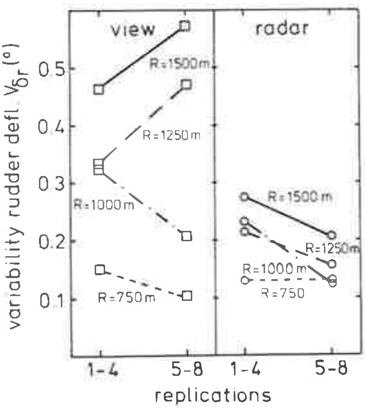


Fig. 4.10 The variability of the relative rudder deflection $V_{\delta r}$ as a function of View, Radar, Range and Replications, averaged over Subjects and Bearing.

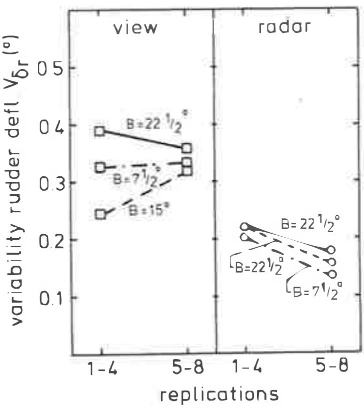


Fig. 4.11 The variability of the relative rudder deflection $V_{\delta r}$ as a function of View, Radar, Bearing and Replications, averaged over Subjects and Range.

### 4.2.4 Discussion

**Summary of results**

The most remarkable result was the weak and unsystematic effect of the factor Replications as shown by the relative rudder deflection.

The $\delta_r$-values showed systematically high values for positions at long range (approx. 1.4) and low values for positions at short range (approx. 0.5) ($F = 83,1$; $df = 3,30$; $p \ll .01$).

The interaction between Presentation and Bearing was due to an excessive high value of $\delta_r$ for positions at a bearing of 22.5° in the View-condition ($F = 4.5$; $df = 2,20$; $p < .05$).

As was expected the $V_{\delta r}$-values showed in the View-condition significant larger values (.33°) than in the Radar-condition (.19°) ($F = 21,0$; $df = 1,10$; $p < .01$). The interaction between Presentation and Range ($F = 6,3$; $df = 3,30$; $p < .01$) showed as a function of increasing Range in the View-condition an increase in $V_{\delta r}$ and in the Radar-condition a constant level.

**No clear practice effects**

The general conclusion from the data is that, after instruction, subjects seem incapable of improving selection accuracy as a function of Replications. This argues against the hypothesis that an accurate motor memory is developed. It may be argued that the number of Ranges and Bearings is too large so as to disturb the development of an accurate motor memory. Yet Schmidt's schema theory in particular predicts a better schema development as there are more "data-points". More diverse movements should deliver more "data-points" and strengthen the relationship between outcome and response specifications. In contrast with this hypothesis, subjects do not adjust to a rule or model. Admittedly, the available practice time is limited. Yet this period should be surely considered as part of a cognitive learning phase and the lack of a clear practice effects in that early learning period indicates that subjects have serious problems in developing a proper motor memory.

A possible interpretation of the lack of practice effects could be that subjects are not capable of accurately developing a rule or internal model on the basis of KR provided from the outcome (**guidance role** of KR) and that KR provided from the correct rudder deflections (**associative role** of KR) could be used more effectively. This will be further detailed in section 4.3. Yet, this interpretation would provide a serious argument against Schmidt's notion that an accurate motor memory is based on a rule or an internal model. It leaves open the possibility that accurate stimulus-response relationships are developed with KR in the associative role. In other words: when the same ranges and bearings - or perhaps a highly limited set of ranges and bearings would be tested over and over again, subjects might acquire the proper rudder deflections, when KR is provided over the correct deflections in associated with the desired targets.

Another possible interpretation of the lack of clear practice is that subjects forget the previously selected control settings because of the time spent between setting and result. A rule might fail to develop since the relation is hampered by short term memory decay. This interpretation is also of considerable importance with regard to the motor memory hypothesis and will be considered in par. 4.3.

Subjects seem to rely more on the Bearing than on the Range of desired positions. An ANOVA on the log $\delta$ scores showed significancy of the factors Range ($F = 16.6$; $df = 3,30$; $p \ll .01$) and Bearing ($F = 186.0$; $df = 2,20$; $p \ll .01$) and not of the interaction between Range and Bearing ($F = 1.8$; $df = 6,60$; n.s.). A model was fitted as follows: $\log \delta = -0.76 \log \text{Range} + 0.93 \log \text{Bearing} + 2.12$. It indicates the relative importance of the Bearing for rudder selection.

As a function of Range, small deflections are overestimated and large deflections are underestimated. Tversky and Kahneman (1974) concluded that when subjects make judgements in situations of uncertainty, over- and underestimation of respectively small and large values is quite a universal symptom. They suggest adjustment to "an anchor", at least when such a relevant value is available in situations of uncertainty. Poulton (1973) has also shown, that responses are influenced by the range of stimuli and responses, and that range effects generally involve a central tendency. The present results show a similar bias towards a central value.

Results support the assumption of a rough instead of an accurate motor memory. This rough motor memory approximates the correct rudder deflections for Bearing of positions, the deflection for Ranges of positions seems to be biased by the average rudder deflection.

**Presentation mode**

The effects of Presentation on the variability of the relative rudder deflection selection are clearly shown by the interaction between

Presentation and Range. In the Radar-condition the variability remains approximately constant. In the View-condition the variability increases. The discrimination of desired positions has been analysed for the Radar-condition and results do indeed show significant differences ($p < .01$) between estimates of adjacent bearings or ranges (see Appendix). It is concluded that the recognition of positions is minimally affected by the Radar-condition but is degraded by the View-condition due to the confusion of the perceived distances to positions at long range. The differences between the viewing angles of objects at 1500 and 1250 m Range approximate the threshold of perception.

A possible interpretation of the high values of the relative rudder deflections in the View-condition at Bearing 22.5°, is that this visual angle between the ship's mast and the desired position, when simultaneously observed, is more likely to introduce errors in status perception than visual angles between stimuli of 15° or 7.5° (Haber and Hershenson, 1973; Sanders, 1967). It is suggested therefore, that the subjects in the View-condition for positions at Bearing 22.5°, rely more than in the other conditions on Bearing only, which leads to overestimation of deflections.

## Appendix to section 4.2.2

**Test on the discriminability of desired positions in the Radar-condition**

Four subjects were offered 12 desired positions in random order on a paper sheet. On the paper sheet the radar display with desired and actual position was presented as has previously been described for the Radar-condition. After 5 s the sheet was replaced by one representing the same display but without the desired position (see Fig. 4.12). The memorized desired position had to be drawn by a pencil and produced an estimate of Range and Bearing. The following estimations of Range and Bearing were obtained:

| Estimation of Bearing | | |
|---|---|---|
| Bearing | Estimated Mean | SD |
| 7.5° | 7.12° | 1.22° |
| 15.0° | 13.25° | 2.28° |
| 22.5° | 22.26° | 4.10° |

| Estimation of Range | | |
|---|---|---|
| Range | Estimated Mean | SD |
| 750 m | 739 m | 115 m |
| 1000 m | 947 m | 113 m |
| 1250 m | 1283 m | 141 m |
| 1500 m | 1631 m | 157 m |

In order to answer the question whether subjects are capable of perceiving the desired positions as spatially distinct, t-tests were conducted to compare the various estimates of Bearing and Range. These tests showed significant differences ($p < .01$).

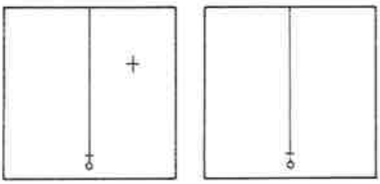

Fig. 4.12 In the first test the desired position was shown on a radar display. After 5 s of exposure this sheet was replaced by one (at right) on which the memorized position had to be indicated by drawing a cross.

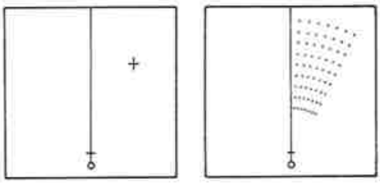

Fig. 4.13 In the second test the desired position was also shown on a paper sheet. After 5 s this sheet was replaced by one (at right) on which 54 positions were presented. The memorized position had to be indicated by marking a dot.

A second test for checking the discrimination of desired positions followed the same procedure except that the second paper sheet on which positions with bearings of 3.75, 7.50, 11.25, 15.00, 18.75, 22.50, 26.25° and ranges of 625, 750, 875, 1000, 1125, 1250, 1375, 1500, 1625 m were presented together. Four subjects had to select the previously shown position from 54 indicated positions (see Fig. 4.13). The following results were obtained:

| Bearing | Estimated Mean | STD |
|---|---|---|
| 7.5° | 6.75° | 1.61° |
| 15.0° | 12.75° | 2.05° |
| 22.5° | 19.37° | 3.66° |

| Range | Estimated Mean | STD |
|---|---|---|
| 750 m | 760 m | 99 m |
| 1000 m | 1062 m | 155 m |
| 1250 m | 1270 m | 128 m |
| 1500 m | 1531 m | 137 m |

Again comparisons of the various estimates of Bearings and Ranges showed significant differences ($p < .01$).

## 4.3 Experiment 4: Effects of knowledge of results on response selection accuracy

### 4.3.1 Introduction

As has been briefly noted the lack of practice shown in Experiment 3 might be caused by the inability of subjects to develop a motor memory on the basis of knowledge of results about the outcome. One suggestion was that KR in such a **guidance role** is used less effectively than in an **associative role.** Hence, the nature of KR might have hampered the development of motor memory. Yet it might also be a special case caused by the time delay between control setting and outcome. Both possibilities were tested in an experiment in which the **Nature** of **KR** (KR-Nature) and the **Moment** of **KR** (KR-Moment) were varied.

**Nature of KR:** In a recent review, Salmoni et al. (1984) have distinguished between the associative and guidance role of KR for motor learning besides its motivational role. It is suggested that the **associative role of KR** corresponds to the old idea that KR promotes associations between specific stimuli and responses. KR strengthens the relation between stimulus and response so that repeated practice with KR allows the learner to produce the proper specific response to a given stimulus. According to the Law of Effect (Thorndike, 1927) no learning can occur unless KR is provided or unless subjects can generate their own subjective reinforcement as was also argued by Adams (1971) and Schmidt (1975).

In contrast, the **guidance role of KR** refers to information about the response outcome. The subject uses the information to generate a new response on the next trial that is more accurate than the previous one so that performance improves with KR on further trials.

Although Salmoni et al. (1984) have indicated problems with too simple interpretations of KR, the distinction between both KR roles seems to be meaningful. With respect to the development of an accurate motor memory for selecting rudder deflections, it is suggested that the associative role of KR strengthens the bond between desired positions and corresponding rudder deflections so that repeated practice with KR allows for the proper response under the given stimulus condition. Hence, when KR is provided over correct rudder deflections with regard to desired positions and subjects do show performance improvements as a function of practice, a motor memory probably represents a stimulus-response association. The error between correct and actual selected rudder deflection is used for improving the accuracy of the specific **S-R association** (see Fig. 4.14).

When, however, KR can effectively be used in a **guidance role** for learning a **S-R rule**, the error between desired position and actual position is used for improving the accuracy of rudder deflection selection (see Fig. 4.15).

On the one hand, the associative role of KR predicts the forming of specific S-R associations. Within a set of learned S-R couplings it may be speculated that new S-R couplings are approximated to a certain extent by interpolation. On the other hand, the forming of a general S-R rule predicts the correctness of responses to novel stimuli by extra- and interpolation. The idea of an S-R rule matches the recall schema hypothesis of Schmidt since "data-points" as brief storages of S-R relations are primarily used to develop a schema (Schmidt, 1982, p. 594).

The interpretation of the guidance role of KR in developing a schema is not in line with Salmoni's et al. (1984) argument. "... A variant of this idea (the associational role of KR) is presented in schema theory (Schmidt, 1975; 1976). In this situation KR acts to form associations among features of the response so that rules or schemata are created. One of these is called the recall schema which relates commands to the motor system with the outcome of the movement in the environment ..." (Salmoni et al., 1984, p.380). It seems that those authors neglect that KR in developing a schema provides information about the response outcome to generate in a next trial a more accurate response than the previous one and hence plays a **guidance role.** The nature of the recall schema is viewed upon as associative, but rule based, which seems to create a clear paradox.

In the present study it is hypothesised that a motor memory may either have an associative nature or a rule based nature. When improvement of accuracy in selecting rudder deflections as a function of practice is caused by KR over desired and actual outcome, the rule based nature is confirmed. When however, this improvement can be shown on the basis of KR provided over correct and actual response, the associative nature of the motor memory is confirmed.

**Moment of KR:** Due to a short-term memory decay, the moment of KR may also affect the development of a motor memory. If subjects are capable of generating correct responses on the basis of KR presented **immediately** after the moment of selection, performance will improve as a function of practice. In that case it may be concluded that delay time will be a causal factor for the lack of practice since the results of Experiment 3 showed no practice effects.

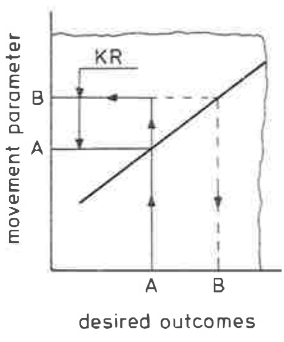


Fig. 4.14 Associative role of KR. From a range of possible desired outcomes, outcome A is selected. Due to an error, movement parameter B is chosen, producing outcome B. KR over the erroneous movement parameter improves performance.

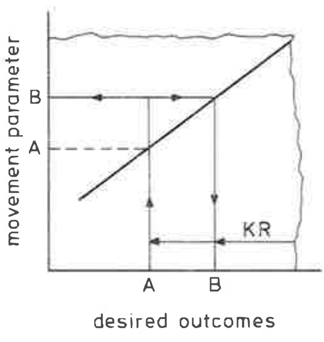


Fig. 4.15 Guidance role of KR. The recall schema to produce desired outcome A, produces outcome B due to an error in the relationship with the movement parameter. KR over the erroneous outcome improves performance as a function of trials (Schmidt, 1975).

### 4.3.2 Method

**Subjects**

Twelve male and 12 female University students took part in the experiment. Their age was between 20-25 years and they had normal or corrected-to-normal vision. They had no experience with ship control.

**Task**

The ship travelled at a constant initial speed of approximately 19 knots on a straight course. The desired position was marked by the symbol of a buoy. At a predetermined range and bearing from the desired position the subject was forced to select one rudder deflection in order to cause collision between the desired position and the vessel's stem. After the selection the subject watched the effects of the rudder deflection on the vessel's position and heading.

In the case of KR-Nature the correct rudder deflection was either presented by integers, shown on the display (KR-Correct Deflection), or was shown by the outcome (KR-Outcome) as the coincidence of stem and buoy symbol. In the case of KR-Moment, KR was immediately shown after selection (KR-Immediate) or delayed until the final position was reached (KR-Delayed). In all conditions the desired position and the change of position and heading was shown in the same way as described in Experiment 4 with regard to the Radar-condition. The View-condition was not considered, since the interest was focussed on the role of KR.

There were twelve possible desired positions as a combination of four ranges (750, 1000, 1250, 1500 m) and three bearings (7.5, 15, 22.5°). The desired position was presented on a radar display in the bridge mock-up.

**Experimental design**

Six factors were combined in the experimental design. The factor KR-N (2 levels) and the factor KR-M (2 levels) were varied between subjects to avoid asymmetrical transfer. Range (R, 4 levels), Bearing (B, 3 levels) and Replications (RE, 8 levels) were varied within subjects. Twenty-four subjects (Ss) were divided into four groups of six subjects each, allocated to the four combinations of the KR-N and KR-M levels. Each group consisted of three male and three female subjects. The testing order was balanced.

**Instrumentation**
Subjects were seated in the bridge mock-up in a similar way as described in Experiment 4. They had the same radar display available as described in Experiment 4. In the condition KR-Immediate the final stem position was immediately presented by a second buoy symbol after the selection of the rudder deflection. In the KR-Correct Deflection condition the correct rudder deflection was presented after deflection by integers on the display (see Fig. 4.16).

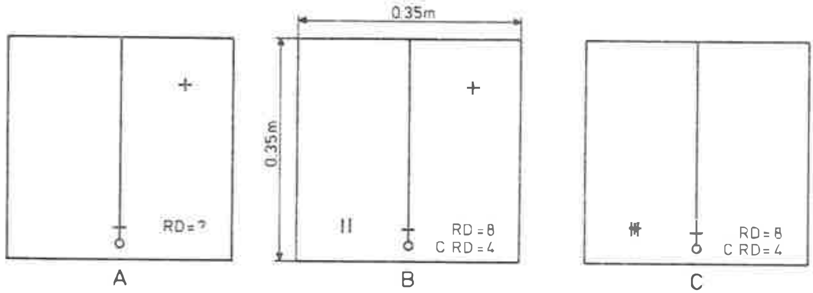


Fig. 4.16 On the radar display the ship's stem is indicated by a short horizontal line and the ship's centre line by a vertical line. The desired position is indicated by a cross (A). The final position, when immediately presented after selection, is depicted as two small vertical lines on 0.5 cm distance (B). The selected rudder deflection (e.g. RD = 8) and the correct rudder deflection (e.g. CRD = 4) are presented on the display when appropriate (B). At C a picture of a completed trial is illustrated.

**Instruction, training and procedure**
These were the same as in the previous experiment.

**Scoring and data analysis**
These were the same as in the previous experiment.

### 4.3.3 **Results**

The relative rudder deflection; $\delta_r$.

Results of an ANOVA are summarized in Table 4.4.

Table 4.4 Summary of an ANOVA concerning $\delta_r$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Nature (N) | 6.2 | 1,20 | <0.05 | NxRE | 1.1 | 7,140 | n.s. |
| Moment (M) | 2.5 | 1,20 | n.s. | MxRE | 0.4 | 7,140 | n.s. |
| NxM | 0.2 | 1,20 | n.s. | NxMxRE | 0.4 | 7,140 | n.s. |
| (Ss within NxM) | | 20 | | (Ss w. NxM)xRE | | 140 | |
| Range (R) | 104.0 | 3,60 | <<0.01 | RxRE | 8.6 | 21,420 | <<0.01 |
| NxR | 3.8 | 3,60 | <0.05 | NxRxRE | 1.9 | 21,420 | <0.01 |
| MxR | 0.3 | 3,60 | n.s. | MxRxRE | 1.2 | 21,420 | n.s. |
| NxMxR | 0.2 | 3,60 | n.s. | NxMxRxRE | 0.8 | 21,420 | n.s. |
| (Ss w. NxM)xR | | 60 | | (Ss w. NxM)xRxRE | | 420 | |
| Bearing (B) | 0.9 | 2,40 | n.s. | BxRE | 0.6 | 14,280 | n.s. |
| NxB | 0.7 | 2,40 | n.s. | NxBxRE | 1.0 | 14,280 | n.s. |
| MxB | 1.3 | 2,40 | n.s. | MxBxRE | 1.1 | 14,280 | n.s. |
| NxMxB | 0.3 | 2,40 | n.s. | NxMxBxRE | 0.9 | 14,280 | n.s. |
| (Ss w. NxM)xB | | 40 | | (Ss w. NxM)xBxRE | | 280 | |
| BxR | 6.4 | 6,120 | <<0.01 | RxBxRE | 1.1 | 42,840 | n.s. |
| NxBxR | 2.4 | 6,120 | <0.05 | NxRxBxRE | 0.6 | 42,840 | n.s. |
| MxBxR | 0.5 | 6,120 | n.s. | MxRxBxRE | 1.2 | 42,840 | n.s. |
| NxMxBxR | 0.3 | 6,120 | n.s. | NxMxRxBxRE | 0.7 | 42,840 | n.s. |
| (Ss w. NxM)xBxR | | 120 | | (Ss w. NxM)xRxBxRE | | 840 | |
| Replications (RE) | 11.4 | 7,140 | <<0.01 | | | | |

The main effect of KR-Nature was significant. In the condition KR-Outcome subjects selected an average $\delta_r$ of .99, in the KR-Correct Response condition the average $\delta_r$ amounted to 1.12. The main effect of Range was highly significant. The significant interaction between KR-Nature and Range showed a smaller underestimation in the KR-Correct Deflection relative to the KR-Outcome condition for positions at short range (see Fig. 4.17). Post-hoc Newman-Keuls test showed that at R = 750 m and R = 1000 m there were significant differences between KR-Correct Deflection and KR-Outcome. The main effect Bearing was not significant. The interaction between Bearing and Range showed high values of relative rudder deflections for positions at short range and large bearing and low values for positions at long range and largest bearing. The factor KR-Nature showed by the interaction between KR-Nature and Bearing and Range in the KR-Correct Deflection condition an decreased underestimation for positions at short range with some differences for each bearing (see Fig. 4.18).

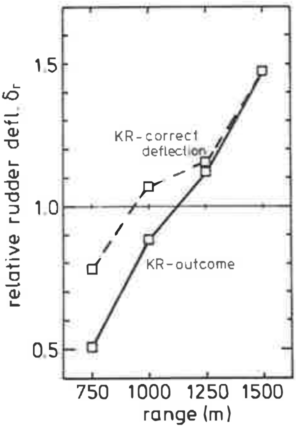


Fig. 4.17 The relative rudder deflection $\delta_r$ as a function of KR-Nature and Range, averaged over KR-Moment, Bearing, Subjects and Replications.

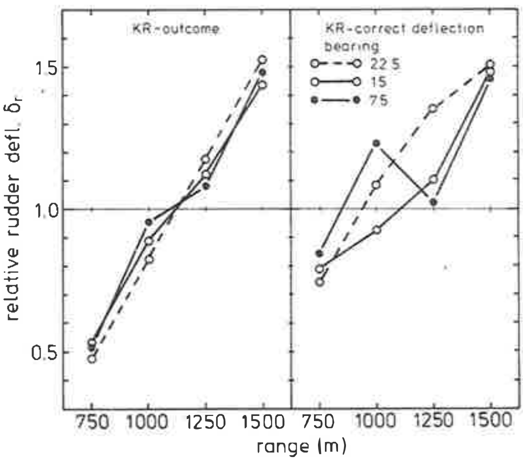


Fig. 4.18 The relative rudder deflection $\delta_r$ as a function of KR-Nature, Range and Bearing, averaged over KR-Moment, Subjects and Replications.

The main effect of RE was highly significant. Averaged over all conditions the overestimation significantly decreased as a function of Replications at R = 1500 m and R = 1250 m (Newman-Keuls test, $p < .01$). The interaction between Range and Replications showed a decrease in the overestimation as a function of Replications. The condition KR-Correct Deflection differed significantly from the condition KR-Outcome in the 8th Replication at R = 750 m (Newman-Keuls test, $p < .01$). The interaction between Nature, Range and Replications is also significant when the first and the second half of the Replications are compared ($F = 4.5$; df = 3.60; $p < .01$). A post-hoc Newman-Keuls test showed significant differences, within the second half of the Replications, of KR-Outcome versus KR-Correct

Deflection (R = 1500 m, n.s.; R = 1250 m; n.s.; R = 1000 m, $p < .01$; R = 750 m, $p < .01$). In Fig. 4.19 the $\delta_r$ is shown as a function of KR-Nature, Range and Replications.

The factor KR-Immediate/Delayed did not show any significant effect.

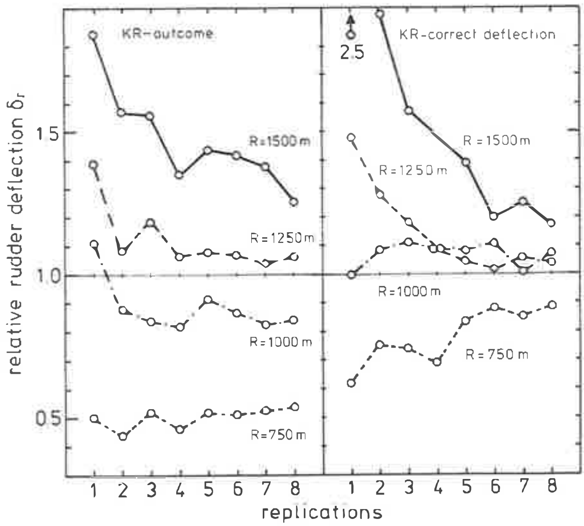


Fig 4.19 The relative rudder deflection $\delta_r$ as a function of KR-Nature, Range and Replications, averaged over KR-Moment, Bearing and Subjects.

**The variability of the relative rudder deflection; $V_{\delta r}$**

Results of the ANOVA are summarized in Table 4.5.

The main effect of KR-Nature is significant. In the condition KR-Outcome the variability of the relative rudder deflection amounted to .22° and in the condition KR-Correct Deflection to .28°. As a function of the increasing Range the variability increases. The interaction between Bearing and Range showed that the variability of deflections for positions at 7.5° bearing does not increase continuously (see Fig. 4.20). The main effect Replications was highly significant. Averaged over the first and second half of the Replications the variability decreased from .32° to .18°. Differences between KR-Immediate/Delayed conditions disappeared as a function of

Replications and decreased between KR-Correct Deflection /Outcome-condition, although these remained significant (see Fig. 4.21).

Table 4.5 Summary of the ANOVA concerning $V_{\delta r}$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Nature (N) | 6.9 | 1,20 | <0.05 | NxRE | 3.8 | 1,20 | n.s. |
| Moment (M) | 2.1 | 1,20 | n.s. | MxRE | 5.1 | 1,20 | <0.05 |
| NxM | 1.2 | 1,20 | n.s. | NxMxRE | 0.1 | 1,20 | n.s. |
| Subjects within NM | | 20 | | (Ss w. NxM)xRE | | 20 | |
| Range (R) | 9.0 | 3,60 | <<0.01 | RxRE | 8.3 | 3,60 | <<0.01 |
| NxR | 0.8 | 3,60 | n.s. | NxRxRE | 1.1 | 3,60 | n.s. |
| MxR | 0.7 | 3,60 | n.s. | MxRxRE | 2.1 | 3,60 | n.s. |
| NxMxR | 0.6 | 3,60 | n.s. | NxMxRxRE | 7.5 | 3,60 | n.s. |
| (Ss w. NxM)xR | | 60 | | (Ss w. NxM)xRxRE | | 60 | |
| Bearing (B) | 2.8 | 2,40 | n.s. | BxRE | 1.5 | 2,40 | n.s. |
| NxB | 1.4 | 2,40 | n.s. | NxBxRE | 1.5 | 2,40 | n.s. |
| MxB | 0.5 | 2,40 | n.s. | MxBxRE | 0.5 | 2,40 | n.s. |
| NxMxB | 1.3 | 2,40 | n.s. | NxMxBxRE | 3.8 | 2,40 | <0.05 |
| (Ss w. NxM)xB | | 40 | | (Ss w. NxM)xBxRE | | 40 | |
| BxR | 2.8 | 6,120 | <0.05 | RxBxRE | 0.6 | 6,120 | n.s. |
| NxBxR | 0.8 | 6,120 | n.s. | NxRxBxRE | 1.7 | 6,120 | n.s. |
| MxBxR | 0.7 | 6,120 | n.s. | MxRxBxRE | 0.7 | 6,120 | n.s. |
| NxMxBxR | 0.5 | 6,120 | n.s. | NxMxRxBxRE | 1.0 | 6,120 | n.s. |
| (Ss w. NxM)xBxR | | 120 | | (Ss w. NxM)xRxBxRE | | 120 | |
| Replications (RE) | 130.0 | 1,20 | <<0.01 | | | | |

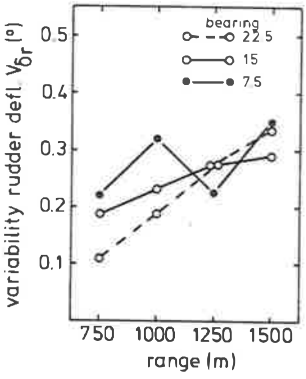


Fig. 4.20 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Range and Bearing, averaged over KR-Nature, KR-Moment, Subjects and Replications.

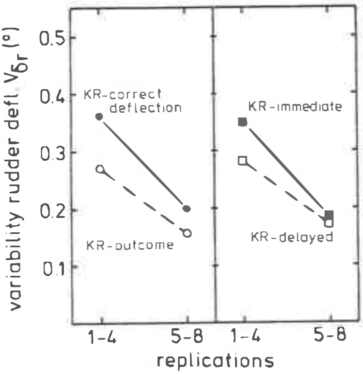


Fig. 4.21 The variability of the relative rudder deflection $V_{\delta r}$ as a function of KR-Correct Deflection, KR-Outcome, KR-Immediate, KR-Delayed and the first and second half of Replications, averaged over Subjects, Range and Bearing.

### 4.3.4 Discussion

**Summary of results**

In contrast with the factor KR-Moment, the factor KR-Nature showed significant effects. The interaction between KR-Nature and Range means an improved relative rudder deflection for positions at short Range in the condition KR-Correct Deflection ($F = 3.8$; $df = 3.6$; $p < .05$). The interaction between KR-Nature and Range and Replications ($F = 1.9$; $df = 21,420$ $p < .01$) showed for the condition KR-Correct Deflection a significant decrease of the over and underestimation of deflections as a function of Replications.

The variability of the relative rudder deflection was significantly smaller in the KR-Correct Deflection condition (.22°) than in the KR-Outcome condition (.28°). There was a significant decrease of the variability from .32° to .18° between the first and the second half of Replications ($F = 130.0$; $df = 1,20$; $p \ll .01$). The interaction between KR-Moment and Replications was significant.

**Nature of KR**

The results show, within the constraints of the present limited practice, that relations between desired positions and rudder deflections are more accurately established when KR is provided in the form of correct responses instead of actual outcomes. Hence, the results confirm the associative role rather than the guidance role of KR. Rudder deflections and desired positions are more accurately related by associations than by a general rule. If an accurate motor memory is developed it will have an associative nature. Subjects cannot effectively use information provided over the realised actual position to generate a new response on a next trial that is more accurate than the previous one.

Yet it has to be mentioned that the rudder selection with KR in an associative role remains slightly inaccurate. As can be seen in Fig. 4.19, the relative rudder deflection at the 8th Replication is smaller in the KR-Correct Deflection condition than in the KR-Outcome condition, but still shows values between 0.9 and 1.2 as a function of Range with a variability of approximately 0.2° (see Fig. 4.21).

**Moment of KR**

The moment of KR does not have a significant effect on the over- and underestimation of rudder deflections, although a slight decrease of this effect as a function of practice is noticeable. When this over- and underestimation effect remains constant as a function of practice, the rough relation between desired position and rudder deflections does not change and implies that no change in the capability of responding is found. It is concluded therefore, that KR over the outcome and the delay time between the moment of response selection and KR provision is of minor importance to the development of accurate relations between desired positions and rudder deflections.

The results of the condition KR-Outcome parallel the findings of Experiment 3, which also showed a motor memory approximating the correct rudder deflections for Bearing of positions with those of rudder deflections for Ranges of positions biased by the averaged rudder deflection.

## 4.4 Summary

In this chapter the accuracy of selecting one rudder deflection to approach a desired position was investigated as part of a ship control task. The requirement of selecting one and only one control setting resembles that component of control performance that is based on motor memory. The development of an accurate relation between rudder deflections and desired positions as a function of practice would be in line with the accurate motor memory hypothesis. Continuing inaccurate selection as a function of practice would be consistent with the rough motor memory hypothesis.

In a first experiment the hypothesis was tested that selection of a single rudder deflection in approaching a desired position is based on an accurate motor memory. In addition, the effects of View and Radar as different modes for stimulus presentation were tested. The general conclusion from the data is that after instruction, subjects seem incapable of improving selection accuracy as a function of Replications. This argues against the hypothesis that an accurate motor memory is developed. In contrast with Radar, View degraded the accuracy of rudder selection for positions at long range, but this effect was of minor importance compared with the over- and under-estimation of small respectively large required rudder deflections as a function of Range of positions. Subjects seemed to rely merely on the Bearing of positions, whereas the deflections for Ranges of positions seemed to be biased by the average rudder deflection.

In a second experiment, the development of motor memory was further analysed with regard to the role of KR. It was hypothesized that motor memory could have an associative or a rule based nature. In addition, the effects of the moment of KR provision (immediate or delayed) were determined. Results showed that subjects could improve the accuracy of rudder selection as a function of practice with KR in an associative role. They could not effectively use information provided over the realized actual outcome to generate a new response on a next trial that is more accurate than the previous one. The moment of KR provision did not have a significant effect on the capability of responding.

With regard to the accuracy of tracking performance as observed in Experiment 1, it is unlikely that motor memory has made a large contribution. Since KR in that experiment could have been used only in the guidance role, performance improvement must have been due to the development of other components. Yet it has to be mentioned that a rough motor memory as a behavioural component in the adjustment of the direction and the global size of responses seems to be available after instruction.

# 5 RESPONSE SELECTION IN APPROACHING A DESIRED HEADING

## 5.1 General

According to Spaans (1979), the following phases are completed in order to arrive at a desired future course line (see Fig. 5.1):

a) Selection of a rudder deflection at a wheel-over-point (A) that allows for a turning circle with approximately the desired course line as a tangent (D-E).
b) Selection of a counter-rudder deflection (B) to stop the turn rate so as to arrive at the desired course line with a zero turn rate.
c) Corrective rudder deflections to adjust position, heading and turn rate errors (C).

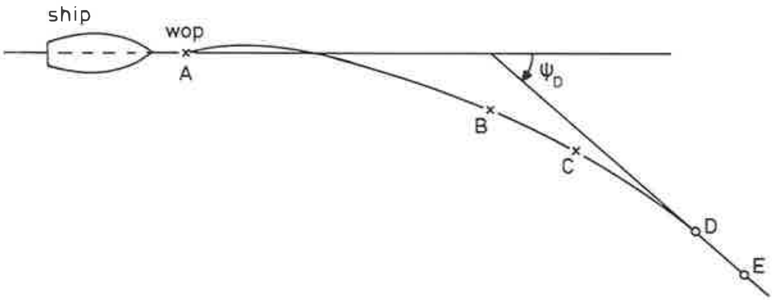


Fig. 5.1 The vessel travels at an initial, constant speed and heading. At the wheel-over-point (WOP) a rudder deflection initiates a turn, resulting in a circle with the desired course line (D-E) approximately as a tangent.

The results of Experiment 3 and 4 have shown that subjects cannot accurately select a single rudder deflection to approach a desired position D. It was concluded that these results support a motor memory hypothesis in the sense of Adams' memory trace rather than Schmidt's recall schema or an internal model. Consequently, accurate manoeuvres seem to be based on closed-loop elements, such as a perceptual memory in the sense of Adams' perceptual trace or Schmidt's recognition memory. Both types of hypothesis contain a reference for evaluating the correctness of performance. A test is presented in Chapter 6.

In the present chapter the question is raised as to whether perhaps some other elements of a course change manoeuvre might be based on an accurate motor memory. The finding that subjects cannot accurately select a single rudder deflection to approach a desired position, could mean that their first rudder deflection only serves to start the turn of the vessel. The resulting turning circle may only roughly approximate the desired course line. The second deflection, counter-rudder, might however constitute an accurate motor memory, which is involved with the prediction of overshoot of a course change manoeuvre (phase "b", see Fig. 5.1), instead of a motor memory involved with the prediction of a ship's path as indicated by a turning circle (phase "a", see Fig. 5.1).

It can be argued that a motor memory for overshoot manoeuvres is relatively simple in comparison with a motor memory for turning circles and therefore it allows the practising of accurate counter-rudder selection. The counter-rudder selection for stopping the turn rate concerns only the control of the heading as a single parameter, whereas a rudder selection for arriving at a desired position involves at least two parameters, defining a position in the flat plane. Moreover, the heading control process can be described by a simplified mathematical model as two first-order differential equations (Nomoto, 1978), whereas the control of the ship's path needs to be described by two additional equations. Hence it seems reasonable to assume that if counter-rudder selection is based on motor memory, its nature is less complex than motor memory involved with rudder selection for desired positions.

To analyse the quality of the motor memory for overshoot manoeuvres, the accuracy of selecting a counter-rudder will be investigated as a control setting to approach a desired course line. In terms of Schmidt's theory, the subject should acquire the relation between 1) initial conditions provided by the difference and the change of difference (turn rate) of the heading error between actual heading and the desired course line; 2) the desired outcome i.e. the desired course line; and 3) response specifications about past outcomes such as affectuated headings. The accurate motor memory hypothesis predicts the improvement of the counter-rudder deflection accuracy as a function of practice by using the ultimate difference between desired course line and effectuated heading as knowledge of results. The turn rate constitutes a parameter of the initial condition, hence it may be expected, on the basis of the results of Experiment 2, that the presentation of turn rate as affected by view or radar also affects the rudder selection accuracy. Both elements, the testing of the accurate motor memory hypothesis and the determination of the effects of turn rate information on rudder selection, will be further detailed in the next sections.

In section 5.2 an experiment is discussed concerning the selection of accuracy of a counter-rudder deflection for approaching a desired course line. In section 5.3 the effects of turn rate information on acquiring a motor memory is investigated.

## 5.2 Experiment 5: The selection accuracy of a counter-rudder deflection

### 5.2.1 Introduction

A simplified control task was designed to test the hypothesis whether selection of a counter-rudder deflection is based on an accurate motor memory as implied by the internal model or on the recall schema of Schmidt's schema theory.

A ship travels at a constant speed and a constant turning rate. The subject is asked to select **one** deflection at a predetermined point in order to arrive at the desired course line with a zero turn rate (see Fig. 5.2). The distance B-D represents the prediction span.

The desired course line is shown by either a simulated radar picture (Radar), a simulated outside view through the bridge windows (View), or by both.

The **accurate** motor memory hypothesis predicts the improvement of the counter-rudder deflection accuracy as a function of practice by using the ultimate difference between desired course line and effectuated heading as knowledge of results. During early practice, inaccurate control settings are expected. In this presumably cognitive phase, the learner attempts various ways of solving the selection problem. During this phase, performance will show a considerable gain that is at least larger than at any other single period of practice. The outcome of trials reflects the result of a single control setting and, as in rapid movement tasks, subjective reinforcement can substitute KR because at each trial the subject is informed about the direction and size of his error.

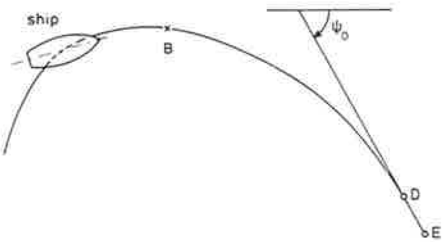


Fig. 5.2 The ship travels at an initial constant speed and a constant turning rate. At B the counter-rudder deflection has to be selected in order to arrive without a zero turn rate at the desired course line, indicated by symbols on locations D and E.

The alternative concerns a rough motor memory as implied by the memory trace of Adams' closed-loop theory. In that theory the motor memory need not be accurate at all, because accurate performance is supposed to be based on a perceptual memory. The inaccurate motor memory hence predicts a rough relationship between desired outcomes and control specifications.

The **accurate motor memory** predicts accurate rudder deflection when the initial conditions as defined by the difference and the change of difference between the actual heading and the desired course line are available. For instance, high turn rates require a larger counter-rudder deflection than low turn rates in order to reduce the same heading errors. Poulton (1967) showed that when tracking a variable rate of movement, the ultimate tracking error, is smaller when the distance between target and controlled marker is kept smaller. Poulton suggests that changes in distance between target and marker are more easy to detect when these distances are smaller (Weber's law). As suggested by Concklin (1957), subjects presumably check the effects of control setting by monitoring the distance change between target and marker. In the ship control task being considered, the perceived difference between actual heading and desired course line may act as a stimulus for deciding about the size of counter-rudder deflections. At a given turn rate, larger heading error (introduced by larger prediction spans between point of selection and desired course line) will produce larger selection errors. Consequently, at given prediction spans, low turn rates will produce larger selection errors than high turn rates.

The presentation mode affects the perception of the initial conditions, in particular the perception of the change of difference between the actual heading and the desired course line. As shown by Wagenaar et al. (1984), motion can be perceived indirectly on the basis of displacement and directly on the basis of velocity. Indirect perception of motion is characterized by a constant Weber fraction, whereas direct perception becomes more efficient as velocity increases. When the change of heading error is expressed in turn rate and amounts to more than the threshold of 5°/min mentioned by Wagenaar, motion can be directly inferred from the target's velocity in a View-condition. When heading and desired course line, however, are presented on a radar display, motion has to be inferred indirectly from changes in displacement. This means that as soon as turn rates become so low that displacements approximate 1 arc min, perception of changes in displacement will be degraded and errors will be introduced in the selection of rudder deflection. Hence, at low turn rates performance in a Radar-condition will be less accurate than in a View-condition.

### 5.2.2 Method

**Subjects**

Nine male and nine female university students took part in the experiment. They were 20-25 years old and had normal or corrected to normal vision. They had no experience with ship control.

**Task**

The ship travelled at an initial speed of approximately 19 knots with a constant turning rate. At a predetermined point from the desired heading line (prediction span), marked by two buoys, the subject had to select a single counter-rudder deflection so as to arrive at the heading line with zero turn rate. After the selection the subject watched the effects of the rudder deflection. The correctness of the selected deflection was evident from the extent that heading line and desired course line coincided. Incorrect deflections resulted in direction changes of turn rates or decreasing turn rates before the ship had reached the desired heading line.

There were four Turn Rates (TR 0.2, 0.4, 0.6 and 0.8°/s) and three Prediction Spans (PS 30, 45 and 60 s). The desired course lines were visible through the windows of the bridge mock-up (View) or on a radar display (Radar) or on both (VR).

**Experimental Design**

Four factors were combined in the experimental design. The factor Presentation (PR, 3 levels) was varied between subjects to avoid asymmetrical transfer effects. The factors Turn Rate (TR, 4 levels), Prediction Span (PS, 3 levels) and Replications (RE, 8 levels) were varied within subjects. Eighteen subjects were divided into three groups of six, each consisting of three male and three female subjects. Each group was allocated to a Presentation-condition. The testing order was balanced.

**Instrumentation**

The subject was seated on a chair at the centre window of the bridge mock-up of the simulator. The subject had a keyboard for typing the rudder deflection in integers between 0 and 35. The selected rudder deflection was displayed just above the keyboard.

In the View-condition, the desired course line was indicated by

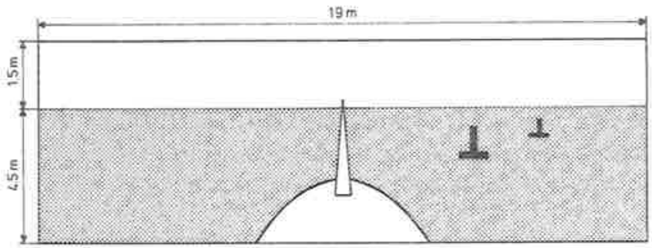


Fig. 5.3 The View-condition shows a perspective view of the foredeck and the surrounding. The picture is presented on a large screen at 9 m distance from the observer. The desired course line is indicated by two buoy symbols.

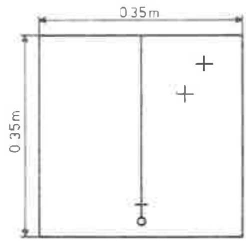


Fig. 5.4 The Radar-condition (at 0.6 m distance from the observer) with a fixed heading line and fixed indications of the stern and the observer's position. The desired course line, indicated by two buoy symbols, moved.

two buoy symbols consisting of a pole of 17 m height and a 17 m wide horizontal pole at the bottom (see Fig. 5.3). Horizon, air, sea surface and foredeck with mast were also visible. The observer's position was 25 m above the sea surface. The buoy symbols had a distance of 600 m between them.

In the Radar-condition, the radar display with a scale of 1:10,000, presented the observer's position, the ship's stem and the ship's heading line. The ship's position was fixed at the bottom of the display in a head-up orientation, the buoy symbols moved (see Fig. 5.4). The buoy symbols were depicted as cross-wires of 1 x 1 cm with a distance of 6 cm between them. The refresh-rate of the radar picture amounted to 24 pictures per minute.

**Instruction and Practice**

The subjects were informed about the effects of counter-rudder deflections on the ship's position and heading. They were told that in order to arrive at the desired course line that at high rates large counter-rudder deflections were needed and at low rates small deflections. Large prediction spans needed small deflections and small spans large deflections.

The subjects watched the ship's position and heading change after the rudder deflection and observed the deviation between desired course and heading line that was finally achieved. This information was available for use in improving the accuracy of rudder selection in the following trials. The subjects were practised in two blocks of 12 runs each. During the first practice block the experimenter checked that the instruction had been understood by way of asking why a particular deflection was selected, how the ultimate deviation was interpreted and commenting if necessary. The second and following blocks were conducted without the presence of the experimenter.

**Procedure**

After the two practising blocks, each subject was tested for 8 successive Replications of 12 trials each.

After the start of a trial, the constant turn rate was observed during 20 s. When finally the location for selecting counter-rudder was reached, the trials were interrupted and continued after selection. Each run was ended when an imaginary line between the stem and location D became perpendicular to the ship's centre line. A new trial was started after 5 s.

Between blocks there were some minutes rest. The subjects were tested between 9.00 - 13.00 hours or 13.30 - 17.30 hours.

**Scoring and Analysis**

$\delta_r$ : the relative rudder deflection. The selected rudder deflection ($\delta$) divided by the desired rudder deflection ($\delta_d$) as a measure of indicating a systematic deviation from the required rudder deflection.

$V_{\delta r}$ : the variability of the relative rudder deflection. The standard deviation of the relative rudder deflection was calculated for the first and the second half of eight replications as a measure for indicating the variability of the selection of rudder deflections.

The desired rudder deflections for arriving at the desired course lines are shown in Table 5.1.

Table 5.1 The desired rudder deflection (°) as a function of Prediction Span and Turn Rate at the location for adjusting counter-rudder.

| | Turn Rate °/s | | | |
|---|---|---|---|---|
| | 0.2 | 0.4 | 0.6 | 0.8 |
| Prediction Span s | | | | |
| 60 | 2 | 4 | 6 | 7 |
| 45 | 3 | 5 | 8 | 9 |
| 30 | 4 | 8 | 11 | 15 |

The scores were subjected to an analysis of variance (ANOVA). The $\delta_r$ was analysed for Presentation (3 levels), Subjects (6 levels), Turn Rate (4 levels), Prediction Span (3 levels) and Replications (8 levels). The $V_{\delta r}$ was calculated for the first and second half of the 8 Replications and the $V_{\delta r}$ was analysed for Presentation (3 levels), Subjects (6 levels), Turn Rate (4 levels), Prediction Span (3 levels) and Replications (2 levels).

### 5.2.3 **Results**

**The relative rudder deflection; $\delta_r$**

Results of an ANOVA are summarized in Table 5.2.

Table 5.2 Summary of an ANOVA concerning $\delta_r$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Presentation (PR) | 0.1 | 2,15 | n.s. | PR x RE | 1.3 | 14,105 | n.s. |
| Subjects within PR | | 15 | | (Ss w. PR)xRE | | 105 | |
| Turn Rate (TR) | 1.7 | 3,45 | n.s. | TR x RE | 0.8 | 21,315 | n.s. |
| PR x TR | 0.9 | 6,45 | n.s. | PRxTRxRE | 0.7 | 42,315 | n.s. |
| (Ss w. PR)xTR | | 45 | | (Ss w. PR)xTRxRE | | 315 | |
| Prediction Span (PS) | 57.7 | 2,30 | <<0.01 | PS x RE | 1.3 | 14,210 | n.s. |
| PR x PS | 2.7 | 4,30 | =0.05 | PRxPSxRE | 1.2 | 28,210 | n.s. |
| (Ss w. PR)xPS | | 30 | | (Ss w. PR)xPSxRE | | 210 | |
| TR x PS | 1.8 | 6,90 | n.s. | TRxPSxRE | 1.4 | 42,630 | n.s. |
| PRxTRxPS | 0.8 | 12,90 | n.s. | PRxTRxPSxRE | 1.8 | 84,630 | n.s. |
| (Ss w. PR)xTRxPS | | 90 | | (Ss w. PR)xTRxPSxRE | | 630 | |
| Replications (RE) | 0.9 | 7,105 | n.s. | | | | |

The main factors Presentation, Turn Rate and Replications were not significant. As was expected, the main factor Prediction Span was significant. Large Prediction Spans showed high $\delta_r$-values and small Prediction Spans low $\delta_r$-values. A Newman-Keuls test showed that the average values for PS = 30 s, PS = 45 s and PS = 60 s significantly differed from each other ($p < .01$). The weak significant interaction between Presentation and Prediction Span revealed lowest $\delta_r$-values at the smallest Prediction Span in the Radar-condition. A Newman-Keuls test showed significant differences at PS = 30 s for Radar versus View and Radar versus View/Radar ($p < .05$) (see Figs. 5.5 and 5.6). There was no significant effect of the factor Replications.

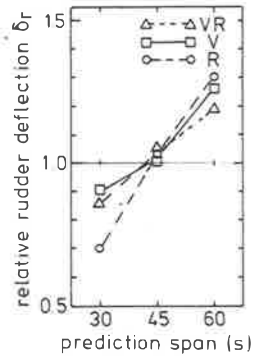


Fig. 5.5 The relative rudder deflection $\delta_r$ as a function of Presentation and Prediction Span, averaged over Turn Rate, Replications and Subjects.

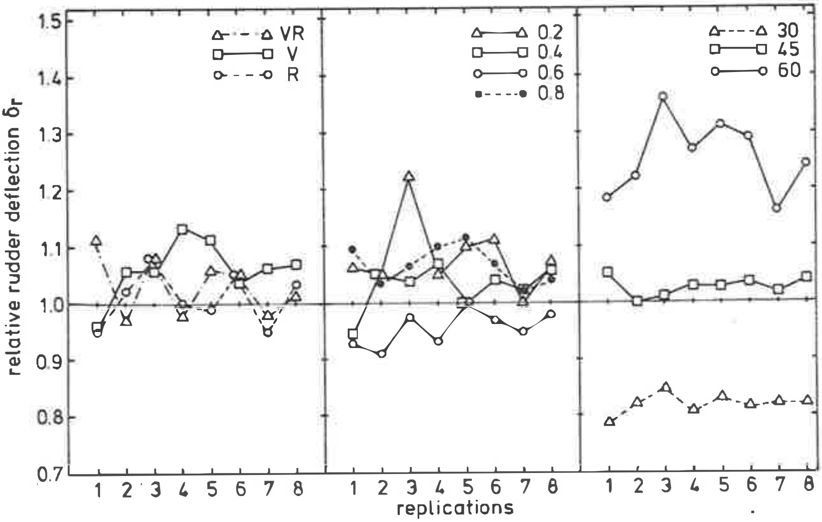


Fig. 5.6 The relative rudder deflection $\delta_r$ as a function of Presentation and Replications, of Turn Rate and Replications, and of Prediction Span and Replications.

**The variability of the relative rudder deflection; $V_{\delta r}$**

Results of an ANOVA are summarized in Table 5.3.

Table 5.3 Summary of an ANOVA concerning $V_{\delta r}$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Presentation (PR) | 0.4 | 2,15 | n.s. | PR x RE | 0.7 | 2,15 | n.s. |
| Subjects within PR | | 15 | | (Ss w. PR)xRE | | 15 | |
| Turn Rate (TR) | 5.9 | 3,45 | <0.01 | TR x RE | 0.6 | 3,45 | n.s. |
| PR x TR | 2.6 | 6,45 | <0.05 | PRxTRxRE | 0.8 | 6,45 | n.s. |
| (Ss w. PR)xTR | | 45 | | (Ss w. PR)xTRxRE | | 45 | |
| Prediction Span (PS) | 12.7 | 2,30 | <<0.01 | PS x RE | 0.3 | 2,30 | n.s. |
| PR x PS | 1.8 | 4,30 | n.s. | PRxPSxRE | 0.6 | 4,30 | n.s. |
| (Ss w. PR)xPS | | 30 | | (Ss w. PR)xPSxRE | | 30 | |
| TR x PS | 1.5 | 6,90 | n.s. | TRxPSxRE | 0.3 | 6,90 | n.s. |
| PRxTRxPS | 0.9 | 12,90 | n.s. | PRxTRxPSxRE | 0.8 | 12,90 | n.s. |
| (Ss w. PR)xTRxPS | | 90 | | (Ss w. PR)xTRxPSxRE | | 90 | |
| Replications (RE) | 6.7 | 1,15 | <0.05 | | | | |

The factor Presentation was not significant. The factor Turn Rate was significant and showed smaller values of $V_{\delta r}$ at high rates. The significant interaction between Presentation and Turn Rate showed at the lowest turn rate in the Radar-condition significantly larger standard deviation of the relative rudder deflection. The View- and View/Radar-condition showed a rather constant performance as a function of Turn Rate, as was expected (see Fig. 5.7). Post-hoc Newman-Keuls test only showed a significant difference at TR = 0.20°/s for Radar versus View and Radar versus View/Radar ($p < .05$).

The factor Prediction Span showed significantly larger $V_{\delta r}$-values with increasing Prediction Span (see Fig. 5.8).

The factor Replications was also significant. The $V_{\delta r}$-value amounted to 0.23° as averaged over the first half of the eight Replications and to 0.19° as averaged over the second half of the Replications (see Fig. 5.9).

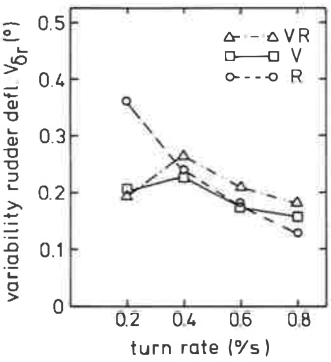


Fig. 5.7 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Turn Rate, averaged over Prediction Span, Subjects and Replications.

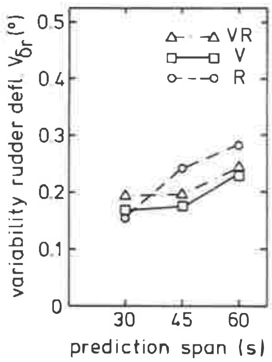


Fig. 5.8 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Prediction Span, averaged over Turn Rate, Subjects and Replications.

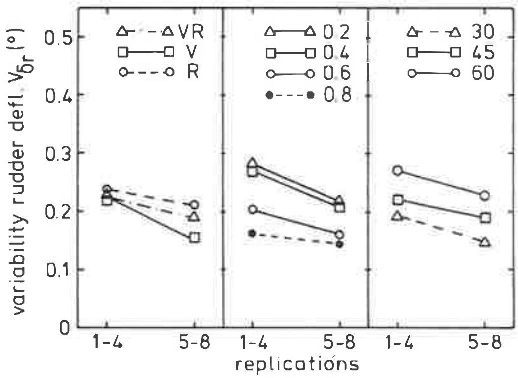


Fig. 5.9 The variability of the relative rudder deflection $V_{\delta r}$ as a function Presentation and Replications, Turn Rate and Replications, and Prediction Span and Replications, averaged over Subjects.

### 5.2.4 Discussion

**Summary of Results**

The factor Replications ($F = 6.7$; $df = 1,15$; $p < 0.05$) only showed one significant effect of interest by the decrease of the variability of the relative rudder deflection from 0.23° to 0.19°. The variability increased with increasing Prediction Span ($F = 12.7$; $df = 3,45$; $p \ll 0.01$) and decreasing Turn Rate ($F = 5.9$; $df = 3,45$; $p < 0.01$).

The interaction between Presentation and Turn Rate showed in the Radar-condition at Turn Rate 0.2°/s a deviation twice as large when compared with the other conditions ($F = 2.6$; $df = 6,45$; $p < 0.05$).

The relative rudder deflection showed high values at large Prediction Spans and low values at small Prediction Spans ($F = 57.7$; $df = 2,30$; $p \ll 0.01$).

**Practice effects**

As shown by the results on the relative rudder deflection, the subjects did not improve their accuracy in arriving at the desired course line. They selected, independent of practice, approximately the correct deflections as a function of Turn Rate. Obviously, subjects could effectively use turn rate information but could not learn to compensate for Prediction Span. Instead, they appeared to generate rudder deflections as a function of Prediction Span that matched the average deflection needed for the range of required deflections. Hence, these results fail to support the accurate motor memory hypothesis for selecting rudder deflections for positions depending on both Turn Rate and Prediction Span.

A significant effect of practice shown by the variability of the relative rudder deflection can be considered as an improvement in performance consistency. In combination with the over- and underestimation shown by the relative rudder deflection, however, the significant decrease of the variability showed that subjects became more consistent in over- and underestimation, supporting the rough motor memory hypothesis.

**Prediction Span, Turn Rate and Presentation**

The results support the expectations on Prediction Span and Turn Rate. Increasing Prediction Span introduces increasing variability of the relative counter-rudder deflection, whereas this variability decreases as a function of increasing Turn Rates.

As shown by the interaction between Presentation and Turn Rates, the variability indicates only in the Radar-condition at low turn rates inaccuracy of selection. This result supports the expectation that, with outside view, the perception of motion can be directly inferred from velocity. In the Radar-condition, when because of the nature of radar velocities are presented by displacements, movements can adequately be inferred except in cases when these displacements cannot be perceived or are only perceived inadequately. In the

View-condition, the lowest turn rate amounted to 0.20°/s which is considerably larger than the threshold of 0.08°/s mentioned by Wagenaar et al. (1984). In the Radar-condition at the lowest turn rate, however, these displacements amounted, averaged over Prediction Span, approximately the threshold of visual acuity and may indeed have degraded performance.

## 5.3 Experiment 6: Effects of a turn rate indicator on selection accuracy

### 5.3.1 **Introduction**

It was found in Experiment 5, that at turn rate 0.2°/s the variability of the relative counter-rudder deflection had a larger value in the Radar-condition in comparison with the other Presentation conditions. It was suggested that this estimate of low turn rates was particularly inaccurate because of the degraded perception of small changes in displacements. If this suggestion is correct, the use of a turn rate indicator should improve performance at low rates and not at high rates where displacement changes are clearly perceptible.

Pew (1966) has shown a performance improvement in tracking tasks where the velocity of the target was indicated by a vector. These results are in accordance with those of Poulton (1967) about performance when tracking a variable rate of movement. Wagenaar (1971) showed the decrement of overshoot of small course change manoeuvres (up to 5°) with large course unstable tankers when a turn rate indicator is used. Yet, the results of these experiments taken together do not reveal whether either preprogrammed or feedback control mechanisms are supported by a turn rate indicator in a ship control tracking task.

In this section an experiment is reported which tests the hypothesis that turn rate information contributes to the selection of a counter-rudder deflection on the basis of an internal model or recall memory (accurate motor memory). These would predict an accurate rudder deflection selection after practice. As argued in section 5.1, the motor memory involved may be conceived of as simple in comparison with one involved with response specifications and desired positions. Hence, when turn rate information is indeed an important cue for the selection of a counter-rudder deflection a Radar-condition with Turn Rate Indicator (Radar-TRI) will show accurate performance, whilst a radar condition without a turn rate indicator (Radar) would show inaccurate performance at low rates because of less clearly perceived changes in displacements.

5.3.2 **Method**

**Subjects**

Six male and six female university students took part in the experiment. They were 20-25 years old and had normal or corrected-to-normal vision. They had no experience with ship control.

**Task**

The ship travelled at an initial speed of approximately 19 knots with a constant turning rate. At a predetermined point from the desired heading line (prediction span), marked by two buoys, the subject had to select **one** counter-rudder deflection so as to arrive at the heading line. After the selection the subject watched the effects of the rudder deflection. The correctness of the selected deflection was evident from the extent to which the heading line and the desired course line coincided.

There were four Turn Rates (TR 0.2, 0.4, 0.6 and 0.8°/s) and three Prediction Spans (PS 30, 45 and 60 s). The desired course lines were indicated by buoy symbols on a radar display (Radar) or on a radar display with a turn rate indicator (Radar-TRI).

**Experimental Design**

Four factors were combined in the experimental design. The factor Presentation (PR, 2 levels) was varied between subjects. The factors Turn Rate (TR, 4 levels), Prediction Span (PS, 3 levels) and Replications (RE, 8 levels) were varied within subjects. The subjects were divided into two groups of six, each consisting of three male and three female subjects. Each group was allocated to a Presentation-condition. The testing order was balanced.

**Instrumentation**

The subject was seated on a chair at the centre window of the bridge mock-up of the simulator. The subject had a keyboard for typing the selected rudder deflection in integers between 0 and 35. The selected rudder deflection was displayed just above the keyboard.

In the Radar-condition, the radar display scale 1:10,000 presented the observer's position, the ship's stem and the ship's heading line. The ship's position was fixed at the bottom of the display in a head-up orientation, the buoy symbols moved (see Fig. 5.10). The buoy symbols were depicted as cross-wires of 1 x 1 cm with a distance of 6 cm between them. The refresh-rate of the radar display amounted to 24 pictures per minute.

In the RAD-TRI-condition, a turn rate indicator was added to the above-mentioned radar display. The turn rate indicator had a horizontal linear scale, 10 cm long. On this scale 1 cm represented 0.1°/s (see Fig. 5.11).

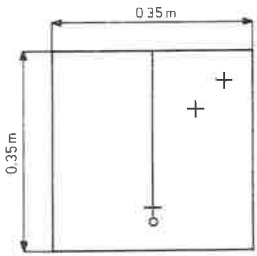


Fig. 5.10 The Radar-condition with a fixed heading line and fixed indications of the stem and the observer's position. The desired course line, indicated by two buoy symbols moved.

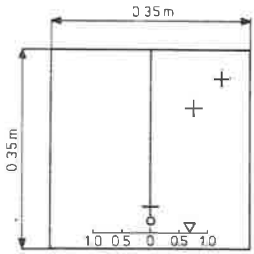


Fig. 5.11 The RAD-TRI-condition, the same display as presented on the left and extended with a Turn Rate Indicator.

**Instruction and Practice**

The subjects were informed about the effects of counter-rudder deflections on the ship's position and heading. They were told that in order to arrive at the desired course line that at high rates large counter-rudder deflections were needed and at low rates small deflections. Large prediction spans needed small deflections and small spans large deflections.

The subjects watched the ship's position and heading change after the rudder deflection and observed the deviation between desired course and heading line that was finally achieved. This information was available for use in improving the accuracy of rudder selection in following trials.

In advance of the 8 Replications, the subjects were practiced in two blocks of 12 trials each. During the first practice block the experimenter checked the use of the instruction by way of asking why a particular deflection was selected, how the ultimate deviation was interpreted and commented if necessary. The second block was conducted without the presence of the experimenter.

**Procedure**

After the two practising blocks, each subject was tested for 8 successive Replications of 12 trials each. Upon the start of a trial it took 20 s before the location for selecting counter-rudder was reached. At that location the trial was interrupted and continued after selection. Each run was ended when an imaginary line between the stem and a buoy symbol became perpendicular to the ship's centre line. A new trial was started after 5 s.

Between the blocks there were some minutes rest. The subjects were tested between 9.00 - 13.00 hours or 13.30 - 17.30 hours.

**Scoring and Analyses**

$\delta_r$ : the relative rudder deflection. The selected rudder deflection ($\delta$) divided by the required rudder deflection ($\delta_d$) as a measure of indicating or systematic deviation from the required rudder deflection.

$V_{\delta r}$ : the variability of the relative rudder deflection. The standard deviation of the relative rudder deflection was calculated for the first and the second half of the eight replications as a measure for indicating the variability of the selection of rudder deflections.

The desired rudder deflections for arriving at the desired course lines are shown in Table 5.4.

The scores were subjected to an analysis of variance (ANOVA). The $\delta_r$ was analysed for Presentation (2 levels), Subjects (6 levels), Turn Rate (4 levels), Prediction Span (3 levels) and Replications (8 levels). The $V_{\delta r}$ was calculated for the first and second half of the 8 Replications and the $V_{\delta r}$ was analysed for PR (2 levels), Subjects (6 levels), Turn Rate (4 levels), Prediction Span and Replications (2 levels).

Table 5.4 The desired rudder deflection $\delta_d$ (°) as a function of Prediction Span and Turn Rate at the location for adjusting counter rudder.

| | Turn Rate °/s | | | |
|---|---|---|---|---|
| | 0.2 | 0.4 | 0.6 | 0.8 |
| Prediction Span s | | | | |
| 60 | 2 | 4 | 6 | 7 |
| 45 | 3 | 5 | 8 | 9 |
| 30 | 4 | 8 | 11 | 15 |

### 5.3.3 Results

**The relative rudder deflection; $\delta_r$**

Results of an ANOVA are summarized in Table 5.5.

Table 5.5 Summary of an ANOVA concerning $\delta_r$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Presentation (PR) | 0.2 | 1,10 | n.s. | PR x RE | 0.3 | 7,70 | n.s. |
| Subjects within PR | | 10 | | (Ss w. PR)xRE | | 70 | |
| Turn Rate (TR) | 4.6 | 3,30 | <0.01 | TR x RE | 0.8 | 21,210 | n.s. |
| PR x TR | 7.8 | 3,30 | <0.01 | PRxTRxRE | 1.3 | 21,210 | n.s. |
| (Ss w. PR)xTR | | 30 | | (Ss w. PR)xTRxRE | | 210 | |
| Prediction Span (PS) | 71.2 | 2,20 | <<0.01 | PS x RE | 0.7 | 14,140 | n.s. |
| PR x PS | 14.9 | 2,20 | <0.05 | PRxPSxRE | 0.7 | 14,140 | n.s. |
| (Ss w. PR)xPS | | 20 | | (Ss w. PR)xPSxRE | | 140 | |
| TR x PS | 3.6 | 6,60 | <0.01 | TRxPSxRE | 1.1 | 42,420 | n.s. |
| PRxTRxPS | 0.8 | 6,60 | n.s. | PRxTRxPSxRE | 1.2 | 42,420 | n.s. |
| (Ss w. PR)xTRxPS | | 60 | | (Ss w. PR)xTRxPSxRE | | 420 | |
| Replications (RE) | 1.0 | 7,70 | n.s. | | | | |

The main factor Presentation was not significant. There was a significant main factor Turn Rate. The significant interaction between Presentation and Turn Rate showed, as a function of Turn Rates, in the Radar-condition at low rates high values and at high rates low values. The Radar-TRI-condition showed a reversed effect. Post-hoc Newman-Keuls test showed at TR = 0.20°/s and TR = 0.80°/s significant differences ($p < .05$) between presentation modes (see Fig. 5.12). This effect seems to be in line with the already mentioned effect of over- and underestimation of responses. The main factor Prediction Span was significant. At small prediction spans there was a low performance score and at large spans a high score, which also suggests a response bias. The significant interaction between Presentation and Prediction Span showed that this effect is smaller in the Radar-TRI-condition than in the Radar-condition (Newman-Keuls test; PS = 60 s, $p < .01$) (see Fig. 5.13). There is no significant effect of the factor Replications (see Fig. 5.14).

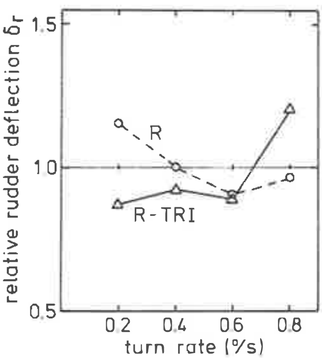


Fig. 5.12 The relative rudder deflection $\delta_r$ as a function of Presentation and Turn Rate, averaged over Subjects, Prediction Span and Replications.

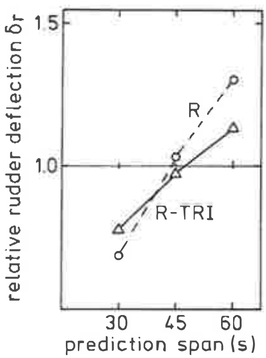


Fig. 5.13 The relative rudder deflection $\delta_r$ as a function of Presentation and Prediction Span, averaged over Subjects, Turn Rate and Replications.

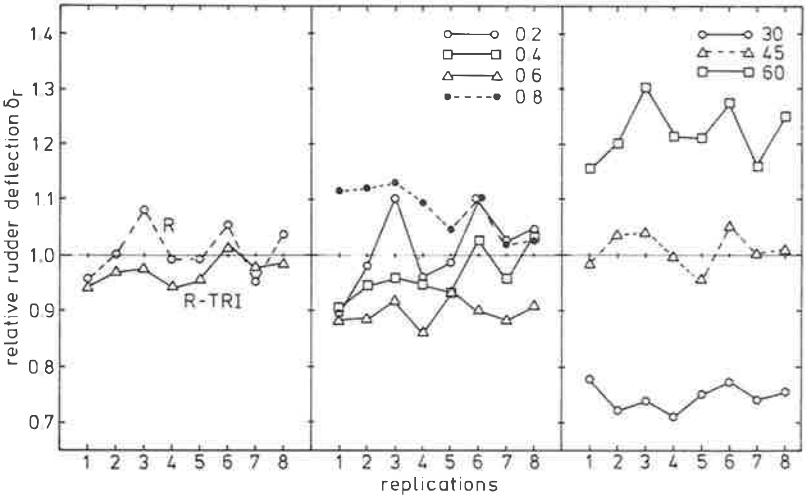


Fig. 5.14 The relative rudder deflection $\delta_r$ as a function of Presentation and Replications, Turn Rate and Replications, Prediction Span and Replications, averaged over Subjects.

**The variability of the relative rudder deflection; $V_{\delta r}$**

Results of an ANOVA are summarized in Table 5.6.

Table 5.6 Summary of an ANOVA concerning $V_{\delta r}$.

| Source | F | df | p | Source | F | df | p |
|---|---|---|---|---|---|---|---|
| Presentation (PR) | 11.4 | 1,10 | <0.01 | PR x RE | 0.1 | 1,10 | n.s. |
| Subjects within PR | | 10 | | (Ss w. PR)xRE | | 10 | |
| Turn Rate (TR) | 7.0 | 3,30 | <0.01 | TR x RE | 0.3 | 3,30 | n.s. |
| PR x TR | 5.4 | 3,30 | <0.01 | PRxTRxRE | 0.5 | 3,30 | n.s. |
| (Ss w. PR)xTR | | 30 | | (Ss w. PR)xTRxRE | | 30 | |
| Prediction Span (PS) | 20.0 | 2,20 | <<0.01 | PS x RE | 0.7 | 2,20 | n.s. |
| PR x PS | 4.2 | 2,20 | <0.05 | PRxPSxRE | 0.6 | 2,20 | n.s. |
| (Ss w. PR)xPS | | 20 | | (Ss w. PR)xPSxRE | | 20 | |
| TR x PS | 0.9 | 6,60 | n.s. | TRxPSxRE | 1.2 | 6,60 | n.s. |
| PRxTRxPS | 0.8 | 6,60 | n.s. | PRxTRxPSxRE | 0.3 | 6,60 | n.s. |
| (Ss w. PR)xTRxPS | | 60 | | (Ss w. PR)xTRxPSxRE | | 60 | |
| Replications (RE) | 2.3 | 1,10 | n.s. | | | | |

The main factor Presentation was significant and showed a smaller variability in the Radar-TRI-condition ($V_{\delta r}$ = 0.14°) than in the Radar-condition ($V_{\delta r}$ = 0.23°). The main factor Turn Rate showed a significant larger deviation at low turn rates than at high turn rates. As shown by the interaction between Presentation and Turn Rate, see Fig. 5.15, the variability was larger at low rates in the Radar-condition than in the Radar-TRI-condition. Post-hoc Newman-Keuls test showed at TR = 0.20°/s and TR = 0.40°/s significant differences ($p < .01$, resp. $p < .05$) between Presentation-conditions. The main factor Prediction Span showed a significant increase of the variability with increasing Prediction Span. The interaction between Presentation and Prediction Span showed in the R-condition a significant increase of the standard deviation as a function of increasing Prediction Span. Post-hoc Newman-Keuls test showed at PS = 45 s and PS = 60 s significant differences ($p < .01$) between Presentation-conditions. The main effect Replications was not significant and there were no significant interactions (see Figs. 5.16 and 5.17).

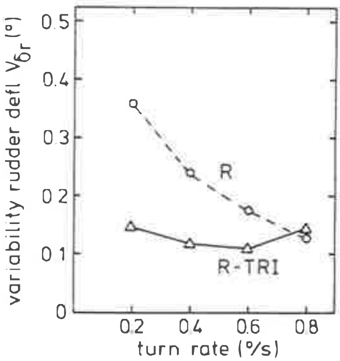


Fig. 5.15 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Turn Rate, averaged over Subjects, Prediction Span and Replications.

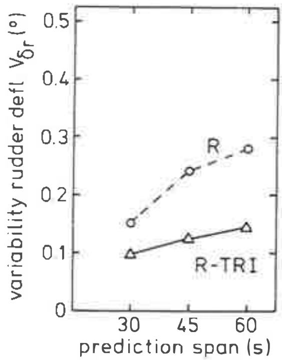


Fig. 5.16 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Prediction Span, averaged over Subjects, Turn Rate and Replications.

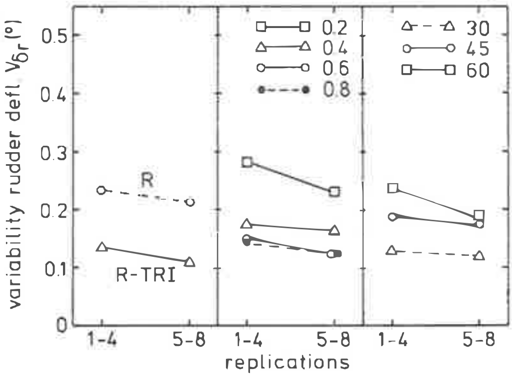


Fig. 5.17 The variability of the relative rudder deflection $V_{\delta r}$ as a function of Presentation and Replications, Turn Rate and Replications, Prediction Span and Replications, averaged over Subjects.

### 5.3.4 Discussion

**Summary of Results**

The factor Replications showed no significant effects. This result parallels finding of the previous Experiment 5.

As shown by the variability of the relative rudder deflection, the Radar-condition shows a larger average variability (0.23°) than the Radar-TRI-condition (0.19°) ($F = 11.1$; $df = 1,10$; $p < 0.01$). As was expected, particularly at a low rate (0.2°/s) the variability is larger in the Radar- than in the Radar-TRI condition ($F = 5.14$; $df = 3,30$; $p < 0.01$). The variability increases with increasing prediction span.

The relative rudder deflection showed over- and underestimation as was also observed in Experiment 6, in particular as a function of Prediction Span ($F = 14.9$; $df = 2,20$; $p < 0.05$).

**No practice effects**

As was also observed and discussed in the previous Experiment 5, the relative rudder deflection shows, as a function of Turn Rate and Prediction Span, single and in their relation to Presentation mode, again effects of over- and underestimation. This finding and the absence of practice effects confirms once more that the accurate motor memory lacks evidence and that only a rough and imprecise motor memory is present. Even in this relatively simple overshoot manoeuvre subjects cannot establish an accurate internal model.

The subjects did not improve their performance as a function of practice. No significant improvement of the relationship between initial conditions, desired outcomes and response specifications was found. Obviously, subjects have available a rough motor memory, which is capable, after instruction, to roughly specify responses.

**Improvement of control by turn rate information**

The variability of the rudder deflection showed in the Radar-TRI-condition at low rate (0.2°/s) significantly smaller values than in the Radar-condition. As was expected, improved turn rate presentation leads to better reproducible response selection, whilst still including the over- and underestimation effect.

Accurate turn rate information contributes to a more consistent selection of counter-rudder deflections at low rates. As was discussed in Chapter 3, anticipation of the ship's position change was poor with radar in a tracking task and might introduce uncertainty in giving rudder calls, initiating errors in the tracking performance. These errors are, as reflected by the larger variability of deflections at low rates in the Radar-condition, due to impaired perception of ship's position changes at low rates. This type of control error typically indicates problems with actions for stabilizing the ship's movements.

## 5.4 Summary

In this chapter two experiments were discussed concerning the response selection in an overshoot manoeuvre. This selection was predicted as being based upon a motor memory which is not as complex as a memory involved in the response selection in a turning circle manoeuvre. Expectations on the results, therefore, tended to a development of an accurate relation between initial condition (e.g. turn rate), desired and past outcomes and response specification as a function of practice. The role of a turn rate indicator was tested since speed, presented as a position or length, enhances speed perception and hence could improve the accuracy of specifying responses.

In Experiment 5, the selection of one counter-rudder deflection in order to arrive at a desired course line was tested. The turn rate constituted an initial condition parameter besides the time between the moment of selection and realisation of the outcome (prediction span). View and Radar were supposed to affect the perception of turn rate at low rates. Results showed, as also observed in Experiment 3, no support of the development of an accurate motor memory. At low rates, View enhanced a more consistent selection of counter-rudder than Radar.

In Experiment 6, the hypothesis was tested that accurate turn rate information improves the accuracy of counter-rudder deflection. Results confirmed the improved consistency of selection when at low rate a turn rate indicator was used.

Results of both experiments failed to support the accurate motor memory hypothesis. Accurate control performance, as shown in Experiment 1, are likely not based on a motor memory as far as counter-rudder selection in an overshoot manoeuvre is involved. Differences in performance between View and Radar found in Experiment 2 and particularly shown by the rudder deflection standard deviation were presumed to be due to the differences in the presentation of ship's position changes. The results of the present experiments confirm that when accurate turn rate information is presented, counter-rudder selection shows low variability. Hence, the more accurate performance in the View-condition of Experiment 2 is likely based on accurate control at low rates, which is sometimes referred to as (Johannsen and Rouse, 1978) control for stabilizing the process under control.

# 6 FEEDBACK IN PURSUIT TRACKING

## 6.1 General

The evidence, so far, runs unanimously counter to the hypothesis that the acquisition of the skill of accurate manoeuvring is due to the development of differentiated motor memory for rudder selection. The results of Experiment 3 showed that when selecting a single rudder deflection in order to approach a desired position, accuracy does not increase as a function of practice trials. In addition, the results of Experiment 5 showed that the selection of counter-rudder deflections required to arrive at a desired heading line is also inaccurate and does not improve as a function of replications. Minor effects of presentation mode were found. Results of Experiment 2 and 5 showed that, among other factors, accurate manoeuvring is depending on the clear presentation of rate of movement (Schuffel, 1984). The better the ship's position changes can be perceived, the better the manoeuvring accuracy can be, particularly at low speeds.

On the basis of these results, the accurate motor memory hypothesis, reflecting Schmidt's recall memory (1975) as well as the internal model notion, does not seem to hold. An alternative is the inaccurate motor memory as reflected in the memory trace of Adams' closed-loop theory (1971). Accurate performance despite an inaccurate motor memory is accomplished by a second component: the perceptual memory. This memory is conceived of as a set of mental references (e.g. tracks, orientations, speeds) which are suitable for evaluating the effects of the rough motor memory. In turn, the motor memory merely determines the direction and the rough size of responses.

The perceptual memory reflects Adams' perceptual trace and Schmidt's (1975) recognition schema. Adams' theory ascribes a movement accuracy improvement to the development of an accurate perceptual trace or, in terms of Schmidt's schema theory, to a recognition schema. Yet, the notion of perceptual trace and recognition schema have similar as well as dissimilar aspects. They are similar in that both memory states are supposed to provide references for evaluating the correctness of effects of actions in terms of sensory consequences. The recognition schema differs from the perceptual trace with regard to the nature of the memory states. Adams' closed-loop theory assumes that there is a unique perceptual trace for each separate movement-desired outcome relation, whereas the schema theory suggests a rule-based recognition schema. This difference is not further explored in the present study, the notions of perceptual trace and recognition schema are no longer distinguished. The set of mental references will be termed perceptual memory.

Given the evidence against practice effects and accurate performance on the basis of motor memory development, improvements of manoeuvring accuracy with practice, as observed in Experiment 1, could be due to the development of a perceptual memory. It was hypothesized in section 3.1 that performance in slow tasks depends on perceptual memory with an increasing need for a motor memory when a manoeuvre increasingly approximates a rapid task. Contributions of a motor memory in such semi-slow tasks could not be excluded on the basis of the results of Experiment 1 and 2. Hence, accurate manoeuvring in slow tasks will mainly depend on perceptual memory, and to a minor part on motor memory.

When performing forcing functions as described in Experiment 1, it can be argued that in the early learning phase subjects aim at the centre of a dike opening (see Fig. 6.1).

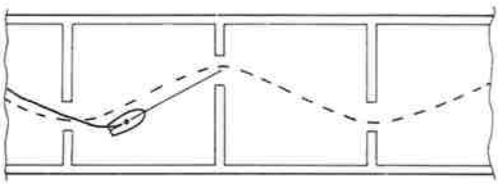

Fig. 6.1 Ground plan of a part of a forcing function from Experiment 1 and 2. The ship should track the dotted line. In the early learning phase the subject aims with the centre line at the middle of an opening.

Yet, at a certain distance from the opening, the subject should initiate a course change in order to enable a correct approach to the next opening. It can be argued that subjects improve tracking accuracy with practice by selecting references (e.g. aimpoints on dike edges and turn rates at various track positions) which enable them to minimize deviations between the desired track and the path travelled.

Each passage of an opening provides knowledge of results about the path travelled. References leading to correct passages are stored and they ultimately compose the perceptual memory. Orientation, as well as tracks and velocities, could contribute to a build-up of a perceptual memory.

There are indications from inland navigation procedures (Breedveld, 1983) that reference tracks are indeed used. In order to improve the path accuracy in river bends, it is suggested that the river bank curvature should be aimed at, with a fixed point of the ship's extended centre line. The use of these procedures is supposed to result in a ship's turning radius, approximately corresponding with the river bend radius (Fig. 6.2).

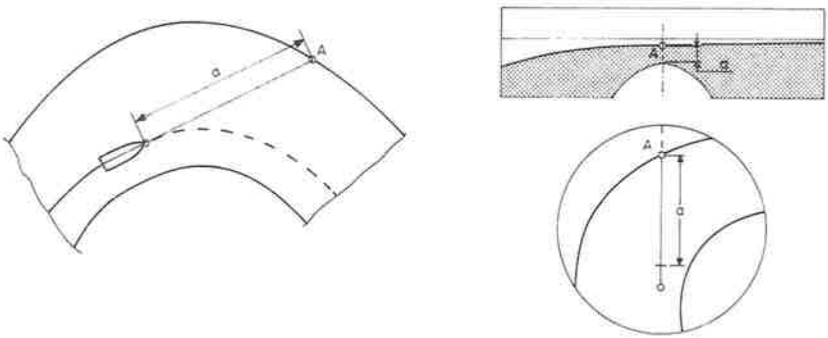


Fig. 6.2 At left a ground plan of a river bend with banks and with a distance "a" at the ship's extended centre line between stem and bank (A). At right the View- and Radar-presentation is depicted.

In the following sections two experiments are discussed concerning the testing of the perceptual memory notion. In these experiments only View-conditions are considered, since it has been shown that such conditions allow for the clear perception of movements and hence enables the ship handler to anticipate the ship's future position on the basis of extrapolating ship's position changes.

In section 6.2 an experiment is described concerning the development of a perceptual memory with practice. The perceptual memory reflects the perceptual trace of Adams' theory and the recognition schema of Schmidt's theory, disregarding the question as to whether such a perceptual memory is unique or rule-based. In section 6.3 the suggestion that accurate ship control in slow tasks is **primarily** based on perceptual memory, will be further detailed.

## 6.2 Experiment 7: Effects of knowledge of results on tracking accuracy

### 6.2.1 Introduction

The hypothesis is tested as to whether subjects, when tracking one specific forcing function a number of times, develop an accurate perceptual memory. The experiment had three KR conditions as independent and manoeuvring accuracy as dependent variable.

In condition KR-S, subjects' knowledge of results about the path travelled was self-generated. This condition closely resembled the condition of Experiment 1 and 2.

In condition KR, subjects attention was drawn to a number of references to evaluate the correctness of the ship's progress by means of aimpoints at various sections of the route. Moreover, after each trial KR was provided about the path travelled by means of a paper sheet on which the reference track and the path travelled were depicted.

In control condition C, the correct (reference) track was continuously visible on the sea-surface during a trial.

In condition C, it is expected that subjects need minimal practice in order to learn how to perform correctly. In fact the task is reduced to simple pursuit tracking with large preview and continuous KR by using the reference track. The subject should aim with a point of the ship's extended centre line (represented by the mast) at the reference track as presented on the sea-surface. Accurate performance is possible to the extent that the distance (change) between aimpoint and desired track can be perceived. In this condition the visible reference track can be considered to constitute a reference for correctness. As in Adams' (1971) theory, motor memory is only needed to initiate the direction and the rough size of a rudder deflection. The effectiveness can be evaluated by the reference and deviations from it can be corrected. In the condition C, no need exists to develop a perceptual memory containing such a reference since the reference is in the outside world. Yet, it cannot be excluded that it still develops to some extent as a result of the visible outside track. This can be tested by removing the reference track after practice. Performance should be about equal to that which is observed in conditions **without** a presented track when perceptual memory has not developed. If it has developed, it should continue at the same level as observed with the reference track.

With regard to condition KR, it is expected that performance will be less accurate than in condition C, because of a less accurate set of references. The number and the nature of references composing the perceptual memory, will obviously affect the ultimate accuracy. Because of the continuous presentation of a reference track in condition C and the discontinuity of the references in condition KR as composed of a limited number of aimpoints, it should be expected that after practice, performance in condition KR is somewhat less accurate. When performance has reached a constant level in condition KR both the Schmidt (1975) and the Adams (1971) theories predict that after KR withdrawal performance first remains constant but decreases in accuracy after some time. The expected constant performance level after KR withdrawal should show that a stable perceptual memory has been established. The expected decrease of accuracy after some time arises from accumulating slightly inaccurate performances which affect the quality and stability of the various references composing the perceptual memory.

With regard to condition KR-S, it is expected that at least more replications are needed to reach performance levels similar to those of condition KR because subjects have to develop a perceptual memory themselves. Yet performance will remain at a lower level to the extent it is less stable than in condition KR. Practice effects, that show ultimately performance levels approximating those of the other conditions, will support the hypothesis of a development of perceptual memory, when development of an accurate motor memory can be excluded.

Contributions of a motor memory will be tested by conducting a trial without visual feedback. In slow tasks without visual feedback the perceptual memory is useless since the expected movements cannot be checked in the environment. Performance depends on motor memory in that case. Consequently, when after practice in condition KR visual feedback is withheld, performance will degrade strongly. Motor memory will be minimally developed since subjects could rely on aimpoints. Condition C will show similar effects. The visible track might however have emphasized motor memory development since the subjects have continuously been involved in minimizing tracking-error. Condition KR-S will also show performance degradation, but as suggested by Crossman and Cooke (1962) subjects initially will try to keep the process within limits and will develop heuristics later on. Hence, motor memory development is possible and will produce less inaccurate performance in a condition without visual feedback.

In all three conditions the use of the rudder as reflected by the standard deviation of the rudder deflections, will show minor differences, since the use is mainly determined by the magnitude of course changes (section 3.2 and 3.3). In condition C, however, subjects will tend to allow minimal tracking error, since in that condition the error is shown most clearly (Sheridan, 1967).

In Table 6.1 the expectations are summarized.

Table 6.1 Overview of expectations regarding the effects of conditions KR-S, KR and C on performance.

| KR conditions | Test on practice effects (Replications 1-19) | Test on perceptual memory (Replications 16, 19-21, 24) | Test on motor memory (Replications 19-20) |
|---|---|---|---|
| KR-S subjects self-evaluation of performance | strong effects finally quite accurate performance | consistent performance | some motor memory development |
| KR KR was provided | moderate effects finally accurate performance | consistent performance | minimal motor memory development |
| C control condition | minimal effects accurate performance | performance degradation | some motor memory development possible |

### 6.2.2 Method

**Subjects**

Nine female and 12 male university students took part. They were 20-25 years old and had normal or corrected-to-normal vision. They had no experience with ship control.

**Task**

The ship travelled at an initial constant speed of approximately 19 knots and a constant number of shaft revolutions on a straight course. The subject should shift to a parallel course at a distance of 333 m. The change should be terminated within a distance of 1332 m (see Fig. 6.3).

The fairway was fully visible from the bridge. The desired track was indicated by dikes and gates as described in Experiment 1 and 2 (see Fig. 6.3). In condition C a reference track was presented as a black line on the sea-surface. In condition KR the subjects were instructed to use three aimpoints on the route as references for correctness of performance and received knowledge of results concerning the path travelled. In condition KR-S the subjects had to select references by themselves and provided their own knowledge of results by observing the success of their passages.

**Experimental Design**

Two factors were factorially combined. KR (3 levels) was varied between Subjects to avoid asymmetrical transfer. The factor Replications (RE, 24 levels) was varied within Subjects. Four male and three female subjects were allocated to a KR level.

**Instrumentation**

The subject was seated in a chair in front of the centre window of the bridge mock-up of the simulator. From there the sea-surface was 25 m below eye level. The subject had a tiller available for adjusting rudder deflections within the limits of 35° port and starboard. The selected deflection was indicated on a dial with an accuracy of 1°. The tiller had similar characteristics as the one described in Experiments 1 and 2.

The fairway was 1000 m wide and had 20 m high dikes on either side. The starting and finishing position were indicated by the centre of a 200-m wide opening in a dike, perpendicular to the fairway axis (see Fig. 6.3).

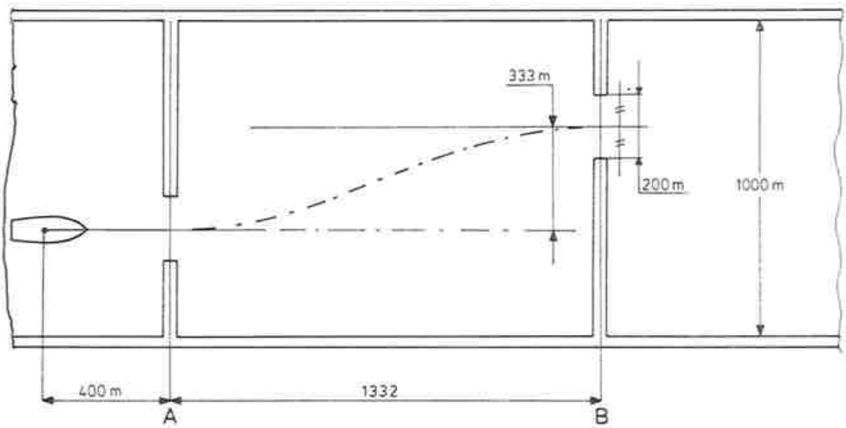


Fig. 6.3 Ground plan of the fairway with start and finish.

**Training and Instruction**

The subjects were trained on the ability to change course of the vessel by practising 20 course change manoeuvres. For that purpose the subjects had to aim at two buoys in succession, both on an initial distance of 1332 m and with a mutual distance of 333 m.

The subjects were asked to pursue a sinewave track so as to pass the centre of the openings with a heading parallel to the fairway axis. Between the openings a smooth course was to be followed. In all conditions the sinewave track was shown on a paper sheet in advance of each trial.

The same sheet was used in condition KR to show the deviation between the travelled path and the desired track and to show 3 references. At 1/4, 2/4 and 3/4 of the route length a heading aim-point was instructed. This was the left edge of the dike opening at 1/4, the middle between the left edge and the centre of the dike opening at 2/4 and the centre of the dike opening at 3/4 of the route length.

**Procedure**

All subjects participated for four hours durin the morning or the afternoon. They were practised for about 45 minutes. Thereafter they performed 19 trials in one block of 10 and one of 9 trials each. A block took approximately 45 minutes. The **20th** trial was conducted **without** outside view (Replication 20). Subjects were told about the withdrawal of visual feedback just at the start of the 20th replication.

These trials were followed by a final block of 4 trials. In these trials the reference track was removed in condition C, and KR was withdrawn in condition KR (Replications 21-24). In all conditions the fairway lay-out remained unchanged.

**Scoring and Analysis**

RMS : the root-mean-squared error as a measure to indicate the deviation between desired track and path travelled (see Chapter 3).

$l_x$ : phase-shift in the direction of the fairway axis as a measure to indicate lead or lag of the path travelled relative to the desired track (see Chapter 3).

$\sigma_\delta$ : the standard deviation of the rudder deflection to indicate the deviation from the average rudder deflection (see Chapter 3).

The scores were subjected to an Analysis of Variance (ANOVA). Separate ANOVAs were conducted on Replications 1 to 19, 19 and 20, and 16 to 19 versus 21 to 24. The ANOVAs covering Replications 1 to 19 concerned the effects of practice. The ANOVAs 19 and 20 concerned the effects of view versus **no view** on performance accuracy. The ANOVAs 16 to 19 versus 21 to 24 should show effects of removing the desired track at condition C and KR withdrawal at condition KR.

### 6.2.3 **Results**

**RMS-error (Replications 1 to 19)**

Results of an ANOVA are summarized in Table 6.2.

Table 6.2 Summary of an ANOVA concerning RMS-error.

| Source | F | df | p |
|---|---|---|---|
| KR | 12.0 | 2,18 | <<0.01 |
| (Ss within KR) | | 18 | |
| Replications (RE) | 2.9 | 18,324 | <<0.01 |
| KR x RE | 1.3 | 36,324 | n.s. |
| (Ss w. KR)xRE | | 324 | |

The main factor KR was significant. The RMS-error amounted to 27,9 m in condition KR-S, 11,6 m in condition KR, and 10,4 m in condition C. Post-hoc Newman-Keuls tests showed significant differences between KR-S and the other (KR, C) conditions ($p < .01$). The main factor Replications was also significant, but not the interaction between KR and Replications (see Fig. 6.4). The RMS-error in condition KR-S amounted to approximately 42 m and in the other conditions to approximately 15 m at the first trials. These values decreased as a function of practice to approximately 20 m in condition KR-S and to approximately 8 m in the other conditions.

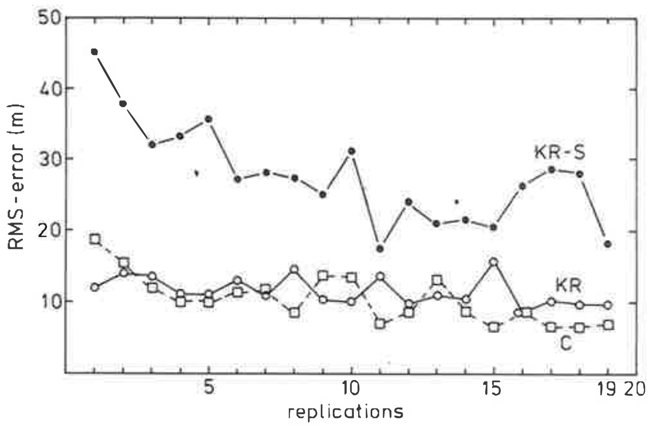


Fig. 6.4 The RMS-error as a function of KR-conditions and Replications, averaged over Subjects.

**Phase-shift $l_x$ (Replications 1 to 19)**

Results of an ANOVA are summarized in Table 6.3.

Table 6.3 Summary of an ANOVA concerning $l_x$.

| Source | F | df | p |
|---|---|---|---|
| KR | 6.1 | 2,18 | <0.01 |
| (Ss within KR) | | 18 | |
| Replications (RE) | 3.9 | 18,324 | <<0.01 |
| KR x RE | 2.8 | 36,324 | <<0.01 |
| (Ss w. KR)xRE | | 324 | |

The ANOVA showed significant main effects. The factor KR showed in condition KR-S that the path travelled lagged behind the desired track. In the other conditions the path travelled resembled approximately the desired track. The significant interaction between KR and Replications revealed a strong effect of practice in condition KR-S. After 19 Replications the initial lag of approximately 175 m was decreased to a lag of approximately 25 m. Post-hoc Newman-Keuls test showed significant differences between KR-S and the other (KR, C) conditions in the trials 1 to 5 ($p < .01$) (see Fig. 6.5).

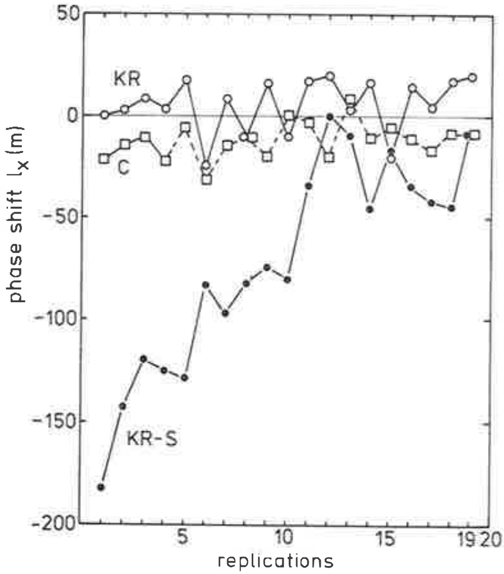


Fig. 6.5 The phase-shift $l_x$ as a function of KR-conditions and Replications, averaged over Subjects. The negative values indicate a lag of the travelled path relative to the desired track.

**SD rudder deflection $\sigma_\delta$ (Replications 1 to 19)**

Results of an ANOVA are summarized in Table 6.4.

Table 6.4 Summary of an ANOVA concerning $\sigma_\delta$.

| Source | F | df | p |
|---|---|---|---|
| KR | 4.5 | 2, 18 | <0.05 |
| (Ss within KR) | | 18 | |
| Replications (RE) | 1.2 | 18,324 | n.s. |
| KR x RE | 1.0 | 36,324 | n.s. |
| (Ss w. KR)xRE | | 324 | |

The main factor KR was significant and showed a standard deviation in condition C of approximately 4.5°, and of approximately 3.3° in the other conditions (Newman-Keuls test: $p < .05$). There was no significant effect of the factor Replications (see Fig. 6.6).

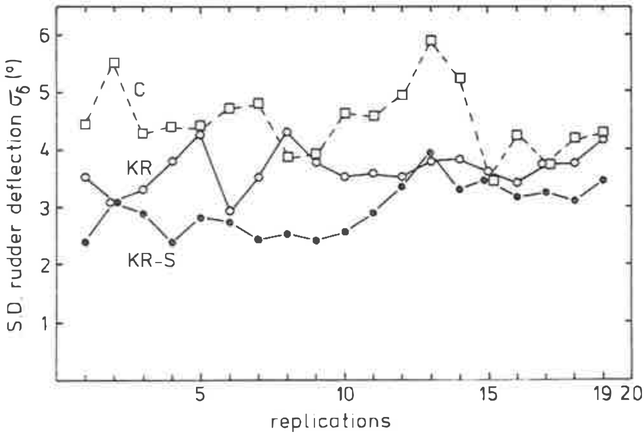


Fig. 6.6 The standard deviation of the rudder deflection $\sigma_\delta$ as a function of KR-conditions and Replications, averaged over Subjects.

**RMS-error (Replications 16-19 and 21-24)**

Results of an ANOVA are summarized in Table 6.5.

Table 6.5 Summary of an ANOVA concerning RMS-error.

| Source | F | df | p |
|---|---|---|---|
| KR | 5.3 | 2, 18 | <0.05 |
| (Ss within KR) | | 18 | |
| Replications (RE) | 3.5 | 1, 18 | n.s. |
| KR x RE | 6.0 | 2, 18 | <0.01 |
| (Ss w. KR)xRE | | 18 | |

The main factor Replications was not significant. The main factor KR was significant. Condition KR-S showed a RMS-value of approximately 23 m, in condition KR this value amounted to approximately 10 m, and in condition C to approximately 16 m. When the desired track was removed in condition C (RE 21-24) the RMS-error significantly increased from approximately 10 m to approximately 22 m (Newman-Keuls test: $p < .05$). When KR was withdrawn in condition KR (RE 21-24) the RMS-error remained constant (see Fig. 6.7).

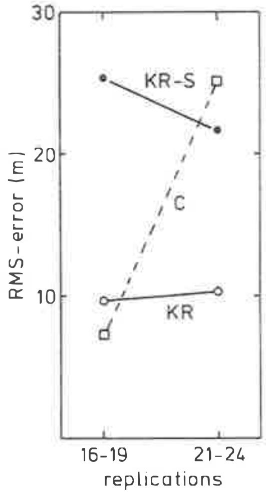


Fig. 6.7 The RMS-error as a function of KR-conditions and Replications, averaged over Subjects.

**Phase-shift $l_x$ (Replications 16-19 and 21-24)**

Results of an ANOVA are summarized in Table 6.6.

Table 6.6 Summary of an ANOVA concerning $l_x$.

| Source | F | df | p |
|---|---|---|---|
| KR | 0.7 | 2,18 | n.s. |
| (Ss within KR) | | 18 | |
| Replications (RE) | 0.3 | 1,18 | n.s. |
| KR x RE | 0.3 | 2,18 | n.s. |
| (Ss w. KR)xRE | | 18 | |

This analysis showed no significant effects of KR and Replications. As shown in Fig. 6.8, the $l_x$-value remained constant, although in condition KR knowledge of results was withdrawn and in condition C the desired track was removed.

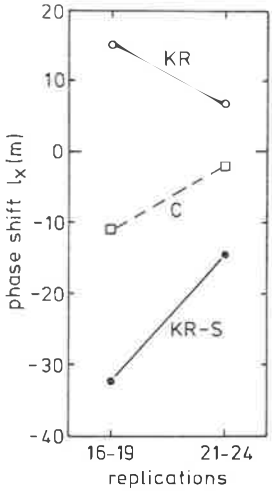


Fig. 6.8 The phase-shift $l_x$ as a function of KR-conditions and Replications, averaged over Subjects.

**SD rudder deflection $\sigma_\delta$ (Replications 16-19 and 21-24)**

Results of an ANOVA are summarized in Table 6.7.

Table 6.7 Summary of an ANOVA concerning $\sigma_\delta$.

| Source | F | df | p |
|---|---|---|---|
| KR | 0.5 | 2, 18 | n.s. |
| (Ss within KR) | | 18 | |
| Replications (RE) | 0.1 | 1, 18 | n.s. |
| KR x RE | 0.4 | 2, 18 | n.s. |
| (Ss w. KR)xRE | | 18 | |

This analysis showed no significant effects of KR and Replications (see Fig. 6.9).

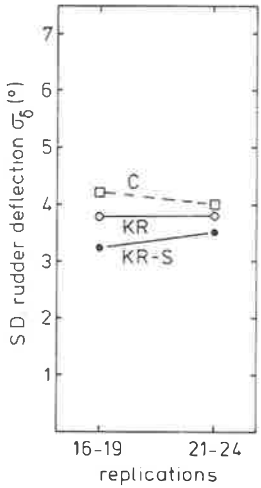


Fig. 6.9 The standard deviation of the rudder deflection $\sigma_\delta$ as a function of KR-conditions and Replications, averaged over Subjects.

**RMS-error (Replications 19 and 20)**

Results of an ANOVA are summarized in Table 6.8.

Table 6.8 Summary of an ANOVA concerning RMS-error.

| Source | F | df | p |
|---|---|---|---|
| KR | 2.1 | 2,18 | n.s. |
| (Ss within KR) | | 18 | |
| Replications (RE) | 91.0 | 1,18 | <<0.01 |
| KR x RE | 5.8 | 2,18 | <0.05 |
| (Ss w. KR)xRE | | 18 | |

The main factor Replications was significant and showed an increase in RMS-values when visual feedback was withheld (Replication 20). As shown by the interaction between Replications and KR, the RMS-error increased in condition KR to approximately 100 m and in condition C and condition KR-S to approximately 60 m. Post-hoc Newman Keuls test showed significant differences at RE 20 between KR and C ($p < .05$), KR-S ($p < .05$) (see Fig. 6.10).

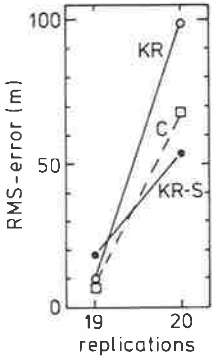


Fig. 6.10 The RMS-error as a function of KR-conditions and Replications, averaged over Subjects.

**Phase-shift $l_x$ (Replications 19 and 20)**
Results of an ANOVA are summarized in Table 6.9.

Table 6.9 Summary of an ANOVA concerning $l_x$.

| Source | F | df | p |
|---|---|---|---|
| KR | 3.5 | 2,18 | =0.05 |
| (Ss within KR) | | 18 | |
| Replications (RE) | 10.4 | 1,18 | <0.01 |
| KR x RE | 7.4 | 2,18 | <0.01 |
| (Ss w. KR)xRE | | 18 | |

The main factor Replications was significant and showed an increased lag between travelled path and desired track when visual feedback was withheld (Replication 20). As shown by Fig. 6.11, the interaction between Replications and KR revealed in condition KR at Replication 20 a lag of approximately 300 m, in condition C of approximately 50 m, and in condition KR-S approximately no lag.

(Newman-Keuls test: KR at RE 20 differed from the other conditions, p < .01).

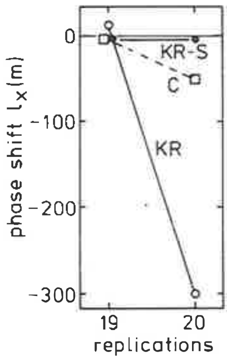


Fig. 6.11 Phase-shift $l_x$ as a function of KR-conditions and Replications, averaged over Subjects.

**SD rudder deflection $\sigma_\delta$ (Replications 19 and 20)**

Results of an ANOVA are summarized in Table 6.10.

Table 6.10 Summary of an ANOVA concerning $\sigma_\delta$.

| Source | F | df | p |
|---|---|---|---|
| KR | 0.3 | 2,18 | n.s. |
| (Ss within KR) | | 18 | |
| Replications (RE) | 9.2 | 1,18 | <0.01 |
| KR x RE | 0.5 | 2,18 | n.s. |
| (Ss w. KR)xRE | | 18 | |

The main factor Replications was significant. The standard deviation of the rudder deflections is smaller in all conditions when no visual feedback is available (see Fig. 6.12).

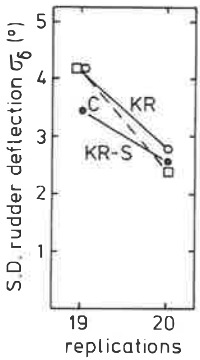


Fig. 6.12 The standard deviation of the rudder deflection $\sigma_\delta$ as a function of the KR-conditions and Replications, averaged over Subjects.

### 6.2.4 Discussion

**Summary of Results**

The ANOVAs of Replications 1-19 showed an increased accuracy in manoeuvring as a function of practice. The RMS decreased, averaged over KR-conditions and Subjects ($F = 2.9$; $df = 11,324$; $p \ll 0.01$), in particular because of a decreased path-lag ($l_x$) in condition KR-S ($F = 2.8$; $df = 36,324$; $p \ll 0.01$). The standard deviation of the rudder deflection showed no effect of practice. The deviation in condition C amounted to 4.5°, and in conditions KR-S and KR to 3.3° ($F = 4.5$; $df = 2,18$; $p < 0.05$).

The ANOVAs of Replications 16-19 and 21-24 showed a significant increase in the RMS-value ($F = 6.0$; $df = 2,18$; $p < 0.01$) when in condition C the reference track was removed from the sea-surface. RMS-error remained approximately constant in condition KR-S, and in condition KR after KR withdrawal. The $l_x$-values and standard deviations did not change as a function of Replications.

The ANOVAs of Replications 19 and 20 revealed a significant increase of RMS-error when visual feedback was withheld ($F = 91.0$; $df = 1,18$; $p \ll 0.01$). This effect was most pronounced in condition KR ($F = 5.8$; $df = 2,18$; $p < 0.05$). The $l_x$ showed a significant increased lag at Replication 20 ($F = 3.5$; $df = 2,18$; $p = 0.05$) and was most pronounced in condition KR ($F = 7.4$; $df = 2,18$; $p < 0.05$).

**Increase of Manoeuvring Accuracy with practice**
The ANOVA of Replications 1-19 showed an immediate accurate tracking performance in condition C. This result is in line with the expectation and shows that subjects can, indeed, pursue a prescribed track with high accuracy (RMS = 8 m; $l_x$ = 12 m). Another expectation was that, when tracking errors are clearly visible rudder deflections will increase. This is supported by the significantly larger standard deviation in condition C relative to the other conditions.

The performance in conditions KR and C was similar. Although in condition KR only a few aimpoints were given as references, this appeared to be sufficient for a performance that is about equally accurate as in condition C. It was expected that in the beginning of the experiment the manoeuvring accuracy would not be as accurate in condition KR as in condition C, and that the accuracy would increase by KR. As has been shown, the initial performance accuracy cannot be improved. Presumably the initial accuracy depends on the fairway geometry and the selection of reference points. This relationship will be discussed in section 6.3.

In comparison to conditions KR and C, tracking performance in condition KR-S showed in the beginning of the experiment a path-lag and large RMS-values. These errors decreased as a function of practice and approached those of conditions KR and C. As was expected, performance accuracy in condition KR-S did not become as accurate as in the other conditions, presumably due to the selection of suboptimal references as a result of the limitations for evaluating the path travelled.

The results of this experiment provide evidence that increase in tracking accuracy as shown in the results of Experiment 1, can be readily ascribed to the development of a perceptual memory. Indirectly, this conclusion is supported by the results of Experiment 3 and 5, which relate to the lack of practice effects when subjects are forced to rely upon developing accurate motor memory.

**Development of a Perceptual Memory**
As shown in condition KR-S of this experiment, subjects are not capable of accurately pursuing a desired track after 45 min of practice on a course change task. In condition C, with a visible reference track, however, subjects immediately perform accurately. Because of the evidence provided by Experiment 3 and 5 that subjects

are incapable of developing an accurate motor memory within 4 hours of practice, it is suggested here that subjects perform accurately by using feedback with a visible track as reference and with a rough motor memory for initiating size and directions of correct rudder deflections. Even when only a few aimpoints are given as references (condition KR), performance approximates the accuracy level of condition C.

The question whether accurate performance is based on the reference track in condition C is answered by removing the track after practice. Comparing the results of RE 16-19 with RE 21-24 it appears that as soon as the desired track is removed in condition C, the RMS-error increases, whereas it remains constant in conditions KR and KR-S. As suggested, the subjects have no need to develop a perceptual memory when a reference track is presented. The increase of RMS-error to the level of values in condition KR-S confirms the idea that references to evaluate correctness of performance are not developed accurately. However, when correctness references are instructed and enhanced by KR, as reflected by condition KR, performance remains at an accurate level after KR withdrawal. Apart from the question about the extent of the contribution of a rough motor memory, it may be concluded that at least a perceptual memory, conceived of as a set of correctness references, contributes effectively to performance accuracy. Apparently, subjects develop such references by themselves, as reflected by the results of condition KR-S. In that condition, however, more time is needed and performance remains somewhat inferior in comparison with condition KR. As expected in the early learning phase of KR-S, subjects develop references by profiting from KR on successive trials which of course will take more time than in conditions KR and C. Besides that, the nature of the subjective KR in condition KR-S is imperfect and will indeed restrict the performance accuracy.

Concerning the contribution of a motor memory, the $l_x$-values in condition C for RE 21-24, show similar values as for RE 16-19. Hence it cannot be concluded that subjects have not learned any rough perceptual and/or motor memory. To determine the contribution of a motor memory to performance accuracy, the RE 19 and 20 are compared and the results are discussed hereafter.

**Contributions of motor memory to the Accuracy of Manoeuvring**

To verify the suggestion made in the previous section that perhaps subjects do not only develop correctness references but also a **rough** motor memory as a function of practice, Replications 19 and 20 were compared. The Replication 20 was conducted without visual feedback and hence the tracking error of Replication 20 showed, in comparison with Replication 19, to what extent motor memory contributed to performance accuracy. The RMS-error showed in all three conditions a significant increase when visual feedback was withheld. The magnitude of this error indicates that motor memory plays a role of minor importance. The standard deviation of the rudder deflection paralleled the expectation. Without clearly indicated control errors, the rudder deflections were smaller.

The accurate $l_x$-value in condition KR-S and the highly inaccurate value in condition KR are of interest. This finding is in line with the expectations that motor memory could be developed somewhat more in condition KR-S than in condition KR. It is argued that subjects in condition KR-S need to develop, in the early learning phase, a rough motor memory to keep the vessel within the fairway boundaries. As suggested by Crossman and Cooke (1962), in the beginning subjects manipulate the system in such a way as to gain necessary information without at the same time losing control of the system. In condition KR-S, as well as in condition C, the $l_x$-value suggests an accurate temporal control setting, due to a certain motor memory development. It is concluded that in conditions KR-S and C a rough motor memory is developed. It has an accurate temporal nature.

## 6.3 Experiment 8: Tracking accuracy in various slow tasks

### 6.3.1 Introduction

The hypothesis is tested that subjects increasingly need to base their control actions on a motor memory as a manoeuvre approximates a rapid task and, on the contrary, increasingly need to base actions on a perceptual memory when a manoeuvre approximates a very slow task. In Experiment 1 and 2, it was not readily possible to distinguish between motor and perceptual memory in slow tasks. It was suggested (section 3.1) that within a range of slow tasks (semi-, slow and very slow tasks), performance could be distinguished that purely should be based on perceptual memory in very slow tasks and that should be based to a certain extent on a motor memory in semi-slow tasks. As in the experiments discussed in Chapter 3, very slow, slow and semi-slow manoeuvres can be defined by forcing functions with respectively low, medium and high indexes.

The present experiment had three forcing functions and three KR-conditions as independent variables and manoeuvring accuracy as dependent variable. The forcing function with index 0.250 represented a slow, with index 0.375 a semi-slow, and with index 0.125 a very slow task. The three KR-conditions resembled those from Experiment 7. In condition KR-S subjects generated their own KR. This condition closely resembled the conditions of Experiment 1 and 2. In condition KR, subjects were instructed to use the three references and were provided with KR over the path travelled. In condition C, the correct (reference) track was continuously visible on the sea-surface during a trial.

**Concerning the semi-slow task**, it was expected that, relative to a slow task, subjects need to base their control actions more on motor memory. This means **in condition C** that subjects will perform in the semi-slow task as accurate as in the slow task. If performance cannot partly be based on motor memory, subjects will show inaccurate manoeuvres relative to the slow task, because feedback control on the basis of the presented reference track will introduce delays in control and hence tracking errors.

**In condition KR** performance is not supposed to differ from condition C, since the results of Experiment 7 indicate that subjects, instructed to use three aimpoints, perform as accurately as in condition C. Particularly, since the aimpoints on the route sections are at shorter distance in a semi-slow than in a slow task, an accurate performance is expected.

**In condition KR-S** performance will be degraded relative to the slow task because of the lack of references. However, when references cannot contribute considerably to performance because feedback cannot effectively function, accuracy of manoeuvring will tend towards the accuracy of the other conditions.

The standard deviation of the **rudder deflections** in all three conditions will show larger values than in slow tasks because of the larger course alterations to be made. Condition C will show, relative to the other conditions, the largest standard deviations, since in this condition the tracking-error is most clearly shown.

**Concerning the very slow tasks**, it was expected that, relative to a slow task, subjects need to purely base control actions on a perceptual memory. This means **in condition** C that subjects will perform with the highest possible accuracy. The desired track in a very slow task tends towards a straight course and tracking accuracy will, relative to a slow task, increase. In a **slow** task, however, performance is supposed to be based also on perceptual memory and hence when the reference track is visible, will show already the maximal tracking accuracy.

**In condition KR** performance will not differ from condition C with regard to the use of aimpoints. However, the same number of aimpoints as in the slow task were used at the longer route section of the very slow task. Each aimpoint should be used at a certain distance from the dike opening. Since larger distances will introduce more variability (see section 4.2), manoeuvring accuracy will tend to decrease.

**In condition KR-S** performance will be degraded relative to the slow task because of the lack of references. Since in the very slow task the accuracy of perceptual memory is of major importance, it is expected that in this condition the largest tracking errors will be found.

The standard deviation of the **rudder deflections** in all three conditions will show smaller values than in a slow task because of the smaller course alterations to be made. Condition C will again show, relative to the other conditions, the largest deviations.

### 6.3.2 **Method**

**Subjects**

The same subjects as described in Experiment 7 took part in the experiment.

**Task**

Except the forcing functions, the tasks resembled those described in Experiment 7. In this experiment two forcing functions were offered. The forcing function with 888 m between the dikes (FFI 0.375) represented a semi-slow manoeuvre, whereas the forcing function with 2664 m distance between the dikes (FFI 0.125) represented a very slow manoeuvre. The third forcing function with 1332 m distance between the dikes (FFI 0.250) represented a slow task. Results of performance on this task were available from Experiment 7.

In condition C the forcing function was visible as a black curve on the sea surface. In condition KR the subjects were instructed to use three aimpoints on the route as references and the subjects were provided with KR over the travelled path. In condition KR-S the subjects had to select references themselves and provided their own KR by observing the success of their passages.

**Experimental Design**

Two factors were combined in the experimental design. The factor KR (3 levels) was varied between Subjects. Each subject repeated four trials on a forcing function. Forcing function (2 levels) was varied within Subjects. The same subjects as described in Experiment 7 were allocated to the KR-levels.

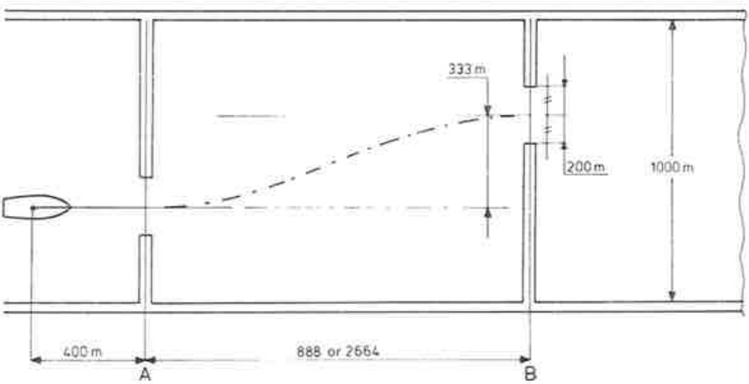


Fig. 6.13 Ground plan of the fairway with start and the desired final position. The semi-slow manoeuvre is represented by the forcing functions with 888 m distance, the very slow manoeuvre by 2664 m distance and the slow by 1332 m distance.

**Instrumentation**

The bridge mock-up and simulator resembled that of Experiment 7, the forcing functions, however, differed in length (see Fig. 6.13).

**Training and Instruction**

The subjects had practised 24 trials on the slow task (see Experiment 7). It was assumed that this practice could be transferred symmetrically within conditions KR, KR-S and C to the semi-slow and the very slow task. The instruction resembled that of Experiment 7.

**Procedure**

The subjects first performed four trials on the semi-slow task and thereafter four trials on the very slow task.

**Scoring and Analysis**

The performance on the semi- and very slow task were compared with the slow task, presented by Replications 16-19. The same scorings were used as described in Experiment 7 and subjected to ANOVAs.

### 6.3.3 **Results**

**RMS-error**

The results of an ANOVA are summarized in Table 6.11.

Table 6.11 Summary of an ANOVA concerning RMS-error.

| Source | F | df | p |
|---|---|---|---|
| KR | 18.5 | 2,18 | <<0.01 |
| (Ss within KR) | | 18 | |
| Forcing function (FF) | 5.6 | 2,36 | <0.01 |
| KR x FF | 4.9 | 4,36 | <0.01 |
| (Ss w. KR)xFF | | 36 | |

The ANOVA showed a significant main factor KR. The main factor Forcing function was also significant. The significant interaction between KR and Forcing function showed accurate tracking in condition C at the slow task (Newman-Keuls test: KR-S different from KR and C, $p < .01$) and at the very slow task (Newman-Keuls test: C different from KR and KR-S, $p < .01$). In the other conditions, except condition KR for the slow task the RMS-error amounted to approximately 20 m or more (see Fig. 6.14).

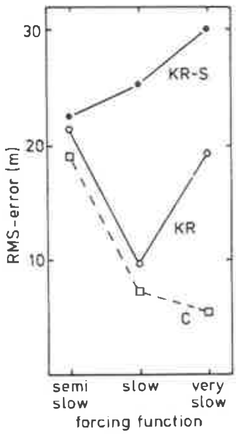


Fig. 6.14 RMS-error as a function of KR-conditions and Forcing function, averaged over Subjects.

**Phase-shift $l_x$**

The results of an ANOVA are summarized in Table 6.12.

Table 6.12 Summary of an ANOVA concerning $l_x$.

| Source | F | df | p |
|---|---|---|---|
| KR | 0.3 | 2,18 | n.s. |
| (Ss within KR) | | 18 | |
| Forcing function (FF) | 0.8 | 2,36 | n.s. |
| KR x FF | 3.1 | 4,36 | <0.05 |
| (Ss w. KR)xFF | | 36 | |

The ANOVA showed a significant interaction between KR and Forcing function. Condition KR-S showed, in contrast to the other condition at semi-slow and slow tasks a lag and at the very slow task a lead error (see Fig. 6.15). Post-hoc Newman-Keuls test showed at the very slow task that KR-S differed from the other conditions ($p < .05$).

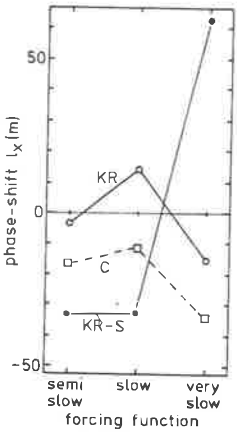


Fig. 6.15 Phase-shift $l_x$ as a function of KR-conditions and Forcing function, averaged over Subjects.

**SD rudder deflection $\sigma_\delta$**

The results of an ANOVA are summarized in Table 6.13.

Table 6.13 Summary of an ANOVA concerning $\sigma_\delta$.

| Source | F | df | p |
|---|---|---|---|
| KR | 5.2 | 2,18 | <0.05 |
| (Ss within KR) | | 18 | |
| Forcing function (FF) | 134.0 | 2,36 | <<0.01 |
| KR x FF | 6.4 | 4,36 | <<0.01 |
| (Ss w. KR)xFF | | 36 | |

This ANOVA showed a significant main factor KR. As was expected the standard deviation amounted to highest values in condition C (Newman-Keuls test: $p < .05$). The main factor Forcing function was also significant. The smaller the distance between dike openings, the larger was the standard deviation. The significant interaction between KR and Forcing function showed as was expected that at the semi-slow task the standard deviations in conditions C and KR are largest (see Fig. 6.16).

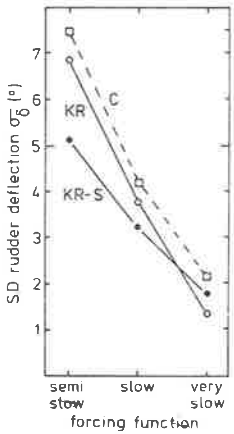


Fig. 6.16 The standard deviation of the rudder deflection $\sigma_\delta$ as a function of KR-conditions and Forcing function, averaged over Subjects.

### 6.3.4 Discussion

**Summary of Results**

The results showed at the semi-slow task, irrespective of KR-conditions, large RMS-errors (approximately 21 m) ($F = 5.6$; $df = 2,36$; $p < 0.01$). At the slow and very slow task, the RMS-error was extremely small in condition C (approximately 6 m) ($F = 4.19$; $df = 4,36$; $p < 0.01$). At the very slow task, on the contrary, condition KR-S showed large RMS-error (approximately 30 m) and a significantly larger (approximately 60 m) positive phase-shift ($F = 3.1$; $df = 4,36$; $p < 0.05$).

The standard deviation of the rudder deflections increased with decreasing distances between dike openings ($F = 134.0$; $df = 2,30$; $p \ll 0.05$). This deviation is largest at the semi-slow task in conditions C and KR ($F = 6.4$; $df = 4,36$; $p \ll 0.01$).

**Semi-slow tasks**

At the forcing function representing the semi-slow task, tracking accuracy showed large RMS-error. As this error is, particularly, in condition C significantly larger than at the slow and very slow task, it can be concluded that feedback control cannot be used effectively and cannot be enhanced by control based on motor memory. This result confirms the expectation that semi-slow and rapid tasks cannot be performed accurately when no accurate motor memory is available, since feedback control cannot be used effectively in such tasks.

As expected, performance in conditions KR and KR-S show similar results and parallel the expectations on ineffective use of feedback.

Use of the rudder, as reflected by the standard deviation of the rudder deflections, is in line with the expectation.

The assumption on symmetrical transfer seems valid. Similar performance in conditions KR and C indicates no asymmetrical transfer of motor memory. The similar performance in conditions KR-S and C shows a role of minor importance with regard to the transfer of perceptual memory in condition KR-S.

**Very slow tasks**

At the forcing function representing the very slow task, tracking accuracy was high in condition C, medium in condition KR and low in condition KR-S. This is in full agreement with the expectations.

In condition C a highly precise performance was expected. This performance could be slightly better (RMS-error) at the very slow task than at the slow task since the forcing function representing the very slow task, is minimally curved.

In condition KR performance is not as precise as in condition C because of the insufficient support of aimpoints at the route-sections but not as imprecise as in condition KR-S with the lack of references.

Results confirm the expectation that tracking accuracy in very slow and slow tasks depend on the accuracy of perceptual memory or instructed references for evaluating correctness of performance.

Rudder use is in line with the expectation.

With regard to symmetrical training transfer, it was assumed that the groups had a rather similar motor memory because of their similar performance in the semi-slow task. Asymmetrical transfer of perceptual memory in condition KR-S cannot be excluded.

## 6.4 Summary

In this chapter the role of feedback in pursuit tracking was analysed. Tracking performance on forcing functions, representing very slow, slow and semi-slow tasks was analysed to determine the contribution of motor and perceptual memory to the accuracy of manoeuvring, which was not readily possible in Experiment 1 and 2.

In Experiment 7, the hypothesis was tested whether subjects develop an accurate perceptual memory when performing slow tasks. Results showed an increase in tracking accuracy with practice that parallels results of Experiment 1 and can be readily ascribed to the development of perceptual memory. Contribution of a motor memory cannot be excluded but with regard to RMS-error this contribution is neglectable.

In Experiment 8, the hypothesis was tested whether subjects need to base their control actions partly on motor memory in a semi-slow task or fully on perceptual memory in a very slow task. Results showed in a very slow task that performance accuracy depends on the accuracy of the references for evaluating performance while in semi-slow tasks feedback cannot be used effectively and introduces inaccurate manoeuvres due to inaccuracy of motor memory.

Results confirm the findings of Experiment 1 and 2, that tracking accuracy in slow tasks depends on feedback control and on the references for evaluating correctness of performance. Tracking accuracy in semi-slow tasks cannot be performed accurately on a combination of perceptual memory and motor memory. Perceptual memory cannot effectively be used in such tasks and accuracy of performance cannot be sufficiently be compensated by a rough motor memory.

# 7 EPILOGUE

Summarizing the main conclusions: experimental results confirmed the hypotheses on perceptual memory and failed to support the accurate motor memory hypothesis. These findings are mainly in line with Adams' closed-loop theory which assumes an accurate perceptual memory and a rough motor memory.

The results of Experiment 1 and 2 showed that experienced mariners (pilots) and novices (students) performed tracking tasks primarily on the basis of feedback. As shown by the results of Experiment 3 and 5, motor memory could not be developed with knowledge of results provided over the control effects. These findings supported the rough motor memory hypothesis. Results of Experiment 7 showed the development of perceptual memory in slow tasks as a function of practice. In faster tasks motor memory could not be used effectively (Experiment 8). Hence, this study confirmed that the accurate control of a ship's position (change) needs to be based on peripheral feedback stimuli, produced by control actions, and a perceptual motor memory. The idea of distinguishing between tasks which are to be performed on the basis of perceptual or motor memory seems, therefore, less meaningful for the tasks which are being considered. The findings support the defence of the closed-loop theory for the tasks under consideration, as persisted by Adams (1976).

The nature of perceptual memory was not explored. Adams' theory assumes a unique perceptual trace for each movement, whereas Schmidt's theory assumes a rule-based recognition schema. Results from Experiment 8, in which subjects with practice in a slow task successively performed an approximately rapid task and a very slow task, showed that accurate performance on the basis of perceptual memory is not transferred accurately between tasks. Therefore, perceptual memory seems to parallel Adams' perceptual trace rather than Schmidt's recognition schema. The nature of the perceptual memory is an important issue, in particular with regard to storage and novelty problems. Schmidt (1976) argued that the schema theory offers a way of acquiring new skills and of storing movement specifications more efficiently than the closed-loop theory, because of its rule-based character. Since the results of the present study do not seem to confirm this aspect of Schmidt's theory, the development of unique perceptual traces should be further scrutinized. The analysis of the transfer of practice between groups trained on various instances versus single instance is a suggested area of further investigation (see also Adams, 1981, p. 104). Adams' theory predicts (see Table 7.1) that perceptual memory outside the distribution of responses which have not been practised is inaccurate, whereas Schmidt's theory predicts accurate performance on the basis of the developed recognition schema.

Table 7.1 Suggestion for further research on the nature of perceptual trace versus recognition schema.

| Group | Training | Transfer |
|---|---|---|
| Experimental | On varied instances of a class of perceptual memories | All groups transfer to one or more new instances of a perceptual memory class |
| Control | On a single instance of the class of perceptual memories | |

The motor memory hypothesis in the sense of Schmidt's schema theory or the internal model notion was not confirmed. A contribution of motor memory to performance accuracy however, could be noticed in the temporal domain. Since in the rudder control lever there was no feedback used from forces acting on the rudder, the results do suppose that feel in the rudder could enhance control accuracy to a larger extent. It could, apart from visual feedback, establish a second, proprioceptive, feedback control loop. In this loop other peripheral feedback stimuli, produced by control actions, could be made effective.

The present study did not cover quantitative aspects of hypotheses as offered by mathematical models (e.g. Pew and Baron, 1978). It is obvious, however, that the data accumulated could be used in a study on quantitative modelling. An explorative study showed encouraging perspectives (Bolt, 1984). Once a structure of behavioural components has been established (e.g. Adams, 1976; Jagacinski, 1978) a quantitative model, reflecting the behavioural structure, can then be matched.

Applications of the results of this study refer to the so-called parallel indexing method (SHELL, 1975; Spaans, 1979b). This method recommends the use of an intended track on a radar display as a reference of desired performance to enhance accuracy of navigation in coastal and terminal navigation. The role of such a performance reference, paralleling the role of perceptual memory, was investigated by Boer and Schuffel (1985) and Boer et al. (1986). In two simulator experiments the effects of an automated charttable and automated parallel indexing on navigational performance and workload of the watchstanding officers was determined. The chart contained the intended track with the ship's most likely position, depicted as a light spot. This intended track was also visible on the radar display. Results showed that manoeuvring accuracy in single-handed operation with the automated charttable and indexing could be improved significantly in comparison with a two-person operated conventional bridge. There was no difference in mental workload between the officers of both bridges.

Future applications tend towards the development of computer use on the ship's bridge for evaluating navigational performance prior to the actual conduct of passages. In particular, the passages in narrow fairways, such as the Barre do Rio Grande (Van Dijk, 1983) could be evaluated by means of computers (Spaans, 1984) in order to enhance the anticipation of ship movements in such specific surroundings. If ship handlers could be trained effectively, it would be on the use of feedback stimuli, produced by control actions, in a specific surrounding (see also Van Hussum, 1981). In this respect Breedveld's suggestion (1983) of using river bends as references to evaluate correctness of performance deserves further attention. Training procedures for steering large ships in bends of fairways as well as a means of improving bend indications, could contribute to the reduction of control variability.

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## HUMAN CONTROL OF SHIPS IN TRACKING TASKS


### SUMMARY

The ship navigation task may be considered as a hierarchically structured task. The voyage is prepared at a planning level. The progress is monitored and controlled at an execution level. A better understanding of the ship handler's performance is needed for various reasons, mainly originating from ongoing trends of automating navigational tasks.

The study is focussed on the formulation and of testing of hypotheses with regard to the monitoring and the controlling of a ship's path in narrow fairways. Because of the large number of variables involved, this navigational task is conceived as a tracking task. A desired track - an externally programmed forcing function - defines a stimulus resulting in an operator's motor response and with that in the adjustment of a rudder deflection. The operator's requirement is to null the tracking-error. Within this scope the hypotheses are tested by means of experiments in a ship manoeuvring simulator. Although that approach allows for the generalization of results, there are few means for falsification. This restriction is compensated by experiments on the ship handler's performance, concerning hypotheses on isolated control settings in a more constrained theoretical framework.

It is suggested that the ship handler's control behaviour is based on two complementary elements: preprogrammed control and feedback control. Notions on preprogrammed control are primarily based on stimulus-related control settings. This element is relevant in manoeuvres (rapid tasks) in which feedback is too slow for accurate performance. Notions on feedback control are primarily based on the evaluation of the results of a control setting. The correctness of performance is continuously checked against a reference (perceptual memory). This element is relevant in those manoeuvres (slow tasks) in which corrections on previous control settings still lead to accurate performance.

Results of tracking experiments with experienced pilots and students, support a feedback rather than a preprogrammed control hypothesis. Results of experiments with students on motor memory (isolated control settings) showed inaccurate selection of rudder

deflections. The accuracy of selection was further scrutinized by analysing effects of knowledge of results on performance. It appeared that the accuracy is improved when knowledge of results is provided over the correct control setting instead of over the results of selected settings. This suggests an associative nature of motor memory.

Results of experiments on feedback control support the hypothesis of perceptual memory. The development of perceptual memory was shown as a function of practice in a tracking task. A slight motor memory development, contributing to the timing of control actions, could be noticed. In faster tasks, motor memory could not effectively be used.

It is concluded that the ship handler's accurate performance is primarily based on perceptual memory with emphasis on the accuracy of references for evaluating the correctness of performance. Preprogrammed control is rather inaccurate.

# HET STUREN VAN SCHEPEN LANGS GEPLANDE TRAJECTEN

## SAMENVATTING

De navigatie van schepen kan worden opgevat als een hiërarchisch geordende taak. De reis wordt voorbereid op een planniveau. De voortgang wordt bewaakt en geregeld op een uitvoeringsniveau. Om verschillende redenen, hoofdzakelijk voortvloeiend uit de zich voortzettende tendens navigatietaken te automatiseren, is een beter inzicht noodzakelijk in de wijze waarop een schip door de mens wordt gestuurd.

Deze studie is gericht op het formuleren en testen van hypothesen over het bewaken en regelen van de baan van het schip in nauwe vaarwegen. Deze navigatietaak wordt vanwege het grote aantal betrokken variabelen als een volgtaak opgevat. Een gepland traject -een van buitenaf opgelegd, te volgen baan - definieert een stimulus die een motorische handeling van de operator en daarmee een roerhoekinstelling tot gevolg heeft. De operator dient de geplande baan nauwkeurig te volgen. Tegen deze achtergrond worden de hypothesen getest met experimenten in een scheepsmanoeuvreersimulator. Hoewel deze benadering het generaliseren van resultaten mogelijk maakt, zijn de mogelijkheden beperkt om de onjuistheid van hypothesen te toetsen. Deze beperking wordt gecompenseerd met experimenten waarin hypothesen over stuurgedrag aan de hand van geïsoleerde regelingrepen worden getoetst in een meer theoretisch toegespitst raamwerk.

Het stuurgedrag wordt verondersteld te zijn gebaseerd op twee elkaar aanvullende elementen: geprogrammeerd sturen en het sturen door terugkoppeling. Noties inzake het geprogrammeerd sturen zijn voornamelijk gebaseerd op regelingrepen die met de stimulus zijn verbonden (motorisch geheugen). Dit element is van betekenis voor manoeuvres waarbij terugkoppeling te traag is voor nauwkeurige prestaties (snelle taken). Noties inzake sturen door terugkoppeling zijn hoofdzakelijk gebaseerd op het evalueren van de gevolgen van een ingreep. De juistheid van de prestatie wordt continu aan een referentie (perceptief geheugen) getoetst. Dit element is van betekenis voor manoeuvres waarbij correcties op eerdere regelingrepen toch tot een nauwkeurige prestatie kunnen leiden (langzame taken).

Resultaten van volgtaakexperimenten met ervaren loodsen en studenten ondersteunen meer een hypothese over sturen door terugkoppeling dan door programmering. Resultaten van experimenten met studenten over het motorisch geheugen (geïsoleerde regelingrepen) toonden een onnauwkeurige roerhoekkeuze. De nauwkeurigheid van de roerhoekkeuze werd verder onderzocht door het analyseren van de invloed van kennis van resultaten op de prestatie. Het bleek dat de nauwkeurigheid werd verbeterd indien kennis van resultaten werd verstrekt over de juiste ingreep in plaats van over de gevolgen van de gekozen ingreep. Op grond hiervan wordt verondersteld dat het motorisch geheugen van associatieve aard is.

Resultaten van experimenten over het sturen door terugkoppeling geven steun aan de hypothese van het perceptieve geheugen. In een volgtaak werd de ontwikkeling van een perceptief geheugen als functie van de oefentijd aangetoond. Een geringe ontwikkeling van het motorisch geheugen, bijdragend aan de tijdstiptheid van regelingrepen, kon worden waargenomen. In snellere taken kon een motorisch geheugen niet effectief worden gebruikt.

Geconcludeerd wordt dat nauwkeurig stuurgedrag voornamelijk is gebaseerd op een perceptief geheugen waarbij de nauwkeurigheid van de referentie voor het evalueren van de juistheid van de prestatie essentieel is. Geprogrammeerd sturen is tamelijk onnauwkeurig.

APPENDIX Description of the simulator

## 1 General

The simulator consists of three main elements:

1 a system for generating an outside view picture of the ship surroundings
2 a mock-up of the ship's bridge
3 a computer system to calculate the ship's movements and the effects of wind and current (see Fig. A1).

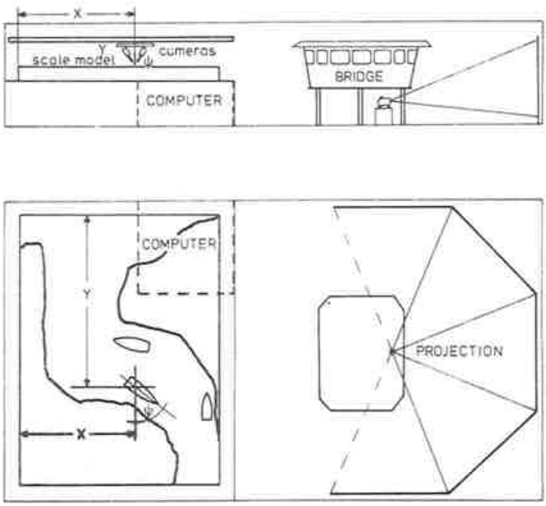


Fig. A1 In a cross-section and a plan view, the three main elements of the simulator are depicted:
- the picture generating system
- the bridge mock-up
- the computer system.

The **picture generating system** contains a set of three TV-cameras. This TV-set, hanging on girders above a modelboard, can move in the horizontal plane with three degrees of freedom. The images taken in the modelboard and representing the ship's surroundings, are projected on three adjacent screens.

The screens, 6.5 m wide and 4.5 m high, are placed around the **bridge mock-up** at a distance of 10.3 m from the observer. Bridge personnel carries out navigational tasks with information inferred from the simulated outside world and from instrumental information in the bridge mock-up.

The **computer system** contains mathematical expressions, describing the ship's manoeuvring behaviour in the horizontal plane. These expressions are mainly differential equations, relating the control actions of bridge personnel, such as rudder deflections and shaft revolutions adjustments, to the ship's movements such as heading and speed. The information is used to update frequently the camera-set position and the bridge instrument values.

## 2 Picture generating system

The three TV-cameras are each equipped with an endoscope. The total horizontal optical angle amounts to approx. 120° and the vertical angle to 30°, with 10° above the horizon.

The characteristics of the TV-cameras are specified as follows:

- video: Telemation, type TMC 1100, black and white, 625 lines
- endoscope: TPD-TNO, depth of focus from 5 mm to infinity
- illumination: 3600 lux on the modelboard.

The video signals are transmitted to three video projectors. The specifications are as follows:

- video: Kalart Victor, black and white, 625 lines
- contrast ratio: 7:1
- luminance: 0.5 $cd/m^2$
- resolution: 8 arc min.

The reduction of contrast (measured by MTF technique) by the loss of definition in the TV-system and in the real-life condition caused by atmospheric straylight is presented in Fig. A2). This figure illustrates that the curve of the loss of contrast as a function of true distance fits reasonably well with that of the simulator. The fitting was obtained by shifting the point r/R = 1 to the point of the axis ≡ 13 cpd. This means that the fitting is true for details of 2.70 m with R = 4000 m (minimum range of moderate visibility) (Van Meeteren, 1977).

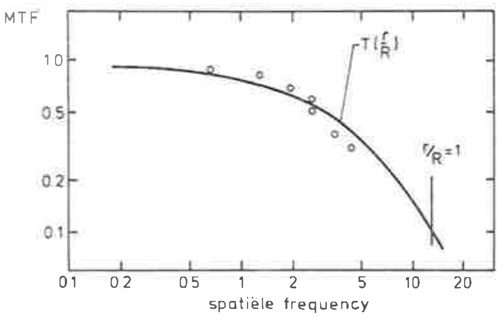


Fig. A2 Comparison of the reduction in contrast, as a function of spatial frequency between simulation (circles) and reality. The Modulation Transfer Function (MTF) is given as a function of a black and white line pattern of various size, the spatial frequency (cpd). The viewing distance r of the contrast T (r) equals the visibility range R at the point 13 cpd for the best fit between reality and simulation.

The camera position has to match the position calculated on the basis of the differential equations, describing the ship's manoeuvring behaviour. With a sampling frequency of 200 ms, the maximal heading error amounts to 0.01° and the maximal position error in the modelboard to 0.6 mm.

Some specifications of the position accuracy are:

| parameter | resolution | max. values | max. error |
|---|---|---|---|
| heading ($\psi$) | 0.01° | 1°/s | 0.2° |
| position (x) | 0.2 mm | 10 mm/s | 0.6 mm |
| position (y) | 0.2 mm | 10 mm/s | 0.3 mm |

The modelboard used in the Experiments 1 and 2 is depicted in Fig. A3. The scale amounted to 1:1000.

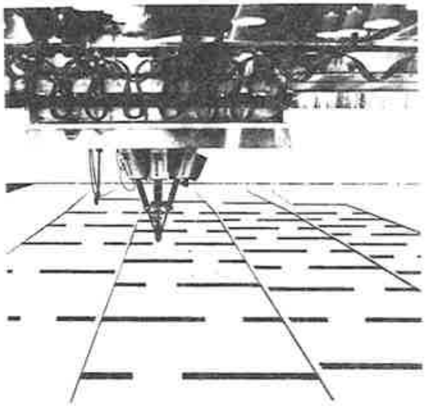

Fig. A3 Picture of the modelboard with forcing functions.

## 3 Mock-up of the ship's bridge

The layout of the ship's brdige is depicted in Fig. A4. The subjects were seated at the front bulkhead on the ship's center line with consoles on both sides and a radar display in front of them.

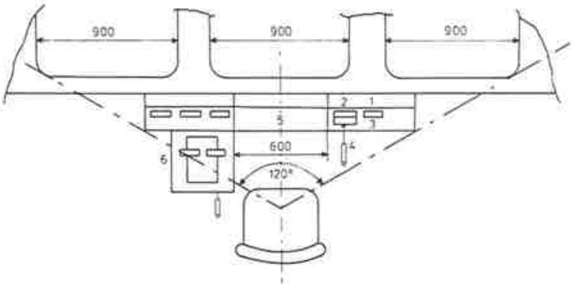


Fig. A4 Consoles in the bridge mock-up.

1 = compass
2 = turn rate indicator
3 = rudder deflection indicator
4 = tiller for rudder control
5 = radar display
6 = consoles without a function in Experiments 1 and 2.

**Note:** Compass and turn rate indicator were only visible in the Experiments 1 and 2 during the familiarising period.

The radar simulator (Van Breda and Van de Kooij, 1977) is specified as follows:

| | |
|---|---|
| Presentation mode | : relative motion, head-up 60% off center to bottom |
| Range | : 1 nautical mile |
| Bearing marker | : parallel to fairway axis |
| Range marker | : indicating ship's stem |
| Heading marker | : indicating actual heading |
| Plan position indicator | : 12" diameter, HP 1321 A, P7 Phosphor |
| Beam rotation | : 24 revolutions per minute |
| Sweep | : 1 ms |

## 4 The computer system

The ship of interest in this study was a 40,000 ton container vessel with the following principal dimensions:

| | |
|---|---|
| $L_{oa}$ | = 225.87 m |
| Width | = 30.50 m |
| Depth | = 16.40 m |
| Draught | = 11.20 m |
| Displacement | = 40,000 ton |
| Propulsion | = 24,208 kW |
| Service Speed | = 22 knots |

The ship's movements are related to a fixed rectangular, clockwise turning axis system (Fig. A5).

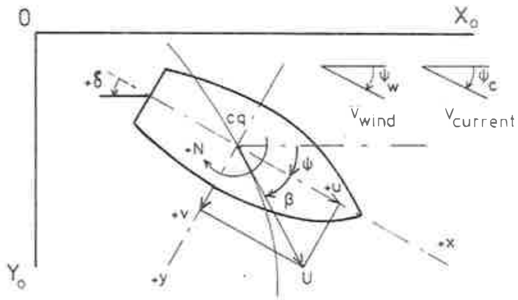


Fig. A5 Coordinate system and definition of positive directions of ship's motion, wind and current.

Only forces acting in the horizontal plane were considered. Rolling, pitching and heaving were left out of consideration, just as the influence of waves and current. The equations of motion for the center point of the ship's mass are:

$$X = m\ (\dot{u} - rv) = X_{hull} + X_{prop} + X_{rudder} + X_{wind}$$

$$Y = m\ (\dot{v} + ru) = Y_{hull} + Y_{prop} + Y_{rudder} + Y_{wind}$$

$$N = I_{ZZ} \cdot \dot{r} = N_{hull} + N_{prop} + N_{rudder} + N_{wind}$$

The hull forces were taken as functions of various parameters:

$$X_{hull} = X\ (u,\ v,\ r,\ \dot{u},\ \dot{v},\ \dot{r})$$

$$Y_{hull} = Y\ (u,\ v,\ r,\ \dot{u},\ \dot{v},\ \dot{r})$$

$$N_{hull} = N\ (u,\ v,\ r,\ \dot{u},\ \dot{v},\ \dot{r})$$

The propellor forces were calculated with

$$S = K_S \cdot \rho\, n^2 D_S^4 \qquad K_S = K_S\ (\lambda) \qquad \lambda = \frac{u\ (1-w)}{n\ .\ D_S}$$

$$X_{prop} = S\ (1-\theta) \qquad \theta = \theta\ (u) \qquad u > 0 \qquad n > 0$$

$$\theta = 0.2 \qquad u > 0 \qquad n < 0$$

$$Y_{prop} = 0$$

The rudder forces were calculated with

$$L_R = C_L \cdot \frac{1}{2} \rho\, u_{RR}^2 \cdot A_R \qquad D_R = C_D \cdot \frac{1}{2} \rho\, u_{RR}^2 \cdot A_R$$

$$u_R = u\,(1-w) + 0.6\, C_a \qquad S = \rho\, \frac{\pi}{4}\, D_S^2\, (V_e + \frac{1}{2}\, C_a)\, C_a$$

$$C_{a_{1,2}} = - V_e \pm \sqrt{V_e^2 + \frac{8\,S}{\pi . \rho . D_S^2}}$$

The windforces were determined by

$$X_{wind} = C_{xw} \cdot \frac{1}{2} \rho_1 \cdot V_{wrel}^2 \cdot A_{wx}$$

$$Y_{wind} = C_{yw} \cdot \frac{1}{2} \rho_1 \cdot V_{wrel}^2 \cdot A_{wy}$$

$$N_{wind} = C_{nw} \cdot \frac{1}{2} \rho_1 \cdot V_{wrel}^2 \cdot A_{wn} \cdot L_{11}$$

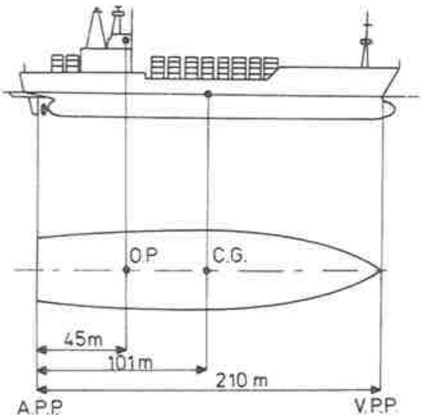


Fig. A6 Sketch of the STS "Soesterberg" as a 40,000 ton container vessel, with subject's position and mass center point relative to the after and forward perpendiculars.

The equations were adapted for shallow-water effects. The added masses in the X, Y and N-equation were enlarged with 25%. The speed-loss in the X-direction caused by shallow-water effects were calculated with the method of Schlichting (Comstock, 1967). The loss of speed amounted to approx. 13% of the maximal value.

A sketch of the ship's general plan is depicted in Fig. A6.

## LIST OF SYMBOLS

| | |
|---|---|
| F | propellor disk area |
| B | moulded ship's breadth |
| $C_a$ | speed increase in propellor race |
| $C_B$ | block coefficient |
| $C_D$ | drag coefficient of rudder |
| $C_L$ | lift coefficient of rudder |
| $K_S$ | propellor thrust coefficient |
| $C_{xw}$, $C_{yw}$, $C_{nw}$ | windforce and moment coefficients |
| $D_s$ | diameter of propellor |
| $D_R$ | drag force of rudder |
| $I_z$ | polar mass inertia moment of ship about vertical axis through c.g. |
| $L(=L_{pp})$ | length of ship between perpendiculars |
| $L_R$ | lift force of rudder |
| N | total yawing moment of exerted on ship |
| $N_{hull}$ | contribution to yawing moment of underwater ship without propellor and without rudder |
| $N_{prop}$ | contribution to yawing moment of propellor |
| $N_{rudder}$ | contribution of yawing moment of rudder |
| $N_{wind}$ | contribution of yawing moment of superstructure due to wind |
| $A_R$ | rudder area |
| $A_{wx}$, $A_{wy}$, $A_{wn}$ | reference wind areas |
| T | ship's draught |
| S | propellor thrust |
| U | ship's speed relative to water |
| $V_c$ | absolute current speed |
| $V_w$ | absolute wind speed |
| $V_{w\,rel}$ | relative wind speed |
| $U_{RR}$ | speed of water relative to rudder |
| $V_e$ | intake velocity of water into propellor |
| X, Y | total force exerted on ship along x- and y-axis respectively |
| $X_{hull}$ + $Y_{hull}$ | contributions to X and Y of underwater ship without propellor and without rudder |
| $X_{prop}$ + $Y_{prop}$ | contributions to X and Y of propellor |
| $X_{rudder}$ | contributions to X and Y of rudder |
| $X_{wind}$ + $Y_{wind}$ | contributions to X and Y or superstructure due to wind |
| W(u) | resistance of ship along x-axis |
| l | distance between c.g. and point at 50 per cent of $\bar{c}$ |
| m | ship's mass |
| n | number of revolutions per second of propellor |
| r | rate of change of heading |
| $u_r$ | component of $U_{RR}$ along x-axis |
| u, $\dot{u}$ | component of U along x-axis, $\dot{u} = du/dt$ |
| v, $\dot{v}$ | component of U along y-axis, $\dot{v} = dv/dt$ |
| $u_{wr}$, $v_{wr}$ | components of $U_{wr}$ along x- and y-axis |
| w | wake fraction |
| $x_o$, $y_o$, $z_o$ | coordinate axes of an earth fixed axis system; positive $z_o$-axis pointing vertically downward |
| $\dot{x}_o$, $\dot{y}_o$ | absolute speed of ship along $x_o$- and $y_o$-axis |
| x, y, z | coordinate axes of a body axis system (principal axes of ship) |
| β | drift angle; positive for negative $v$; tan $\beta = -v/u$ |
| δ | geometric rudder angle relative to x-axis; positive towards port |
| $\delta_e$ | effective rudder angle (angle of attack) |
| $\delta_v$ | direction of $U_{RR}$ relative to x-axis: tan $\delta_v = (v-lr)/u_r$ |
| θ | thrust deduction factor |
| ρ | density of water |
| $\rho_1$ | density of air |
| λ | advance coefficient |
| ψ | course angle; angle between positive $x_o$-axis and positive x-axis; positive going clockwise starting from positive $x_o$-axis |
| $\dot{\psi}$ | rate of change of heading (=r) |
| $\psi_c$ | direction of absolute current speed in $x_o$-$y_o$ axis system |
| $\psi_w$ | direction of absolute wind speed in $x_o$-$y_o$ axis system |
| $\psi_{w\,rel}$ | direction of relative wind speed |

## 5 Validity of the simulator

According to the definition of simulators by the International Marine Simulator Forum (1979), the ship handling simulator is a substitute of the "wheelhouse-man-ship environment system". This means that the manoeuvring characteristics can be simulated on a real-time scale, that the mock-up of the wheelhouse is equipped with instruments and consoles and that the image of the ship surrounding can be related to real-life surroundings, in particular with regard to the visibility conditions. In this respect, the validity of a simulator refers to the extent which the simulator can substitute the real-life system. The technical matters involved, such as the manoeuvring behaviour of the ship, the visibility conditions and the bridge mock-up have been addressed before. Apart from these similarities, the question remains whether mariners perform in a simulator in the same way as in practice (e.g. Wagenaar and Michon, 1968; Truijens et al., 1969). This question was answered for inland water navigation, a condition that closely resembled the conditions of Experiments 1 and 2 of this study. The inland water navigation concerned push-tow control in the Hartelbrug-area. The validation method was based on the assumption that system performance in the simulated conditions should correspond with the experiences of practised mariners in the real-life conditions (Truijens and Schuffel, 1978).

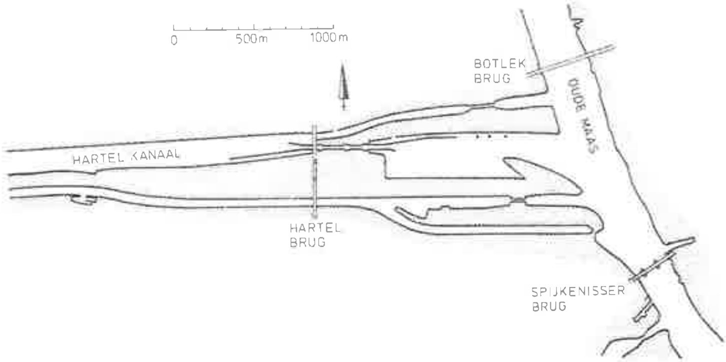


Fig. A7 Existing canal section in which the captains predicted their course as a function of wind, tide and starting position.

To test this, manoeuvres were used which are met in reality and that offer different degrees of difficulty. 64 Situation sketches were drawn up of an existing canal section (Spijkenisserbrug and Hartelsluis) (Fig. A7).

In these situations wind direction (8x), windforce (4x), tide (2x) and starting position (2x) were varied systematically. Each of four subjects (captains) rated 32 of these situations with help of a list with five questions. The equations bore upon the expected feasibility of the passing of the Spijkenisserbrug-area given the mentioned external conditions. After this each subject made 16 runs in the simulator similar to those they had rated beforehand. After each run they had to complete a questionnaire existing of five questions corresponding to those they had answered earlier.

**Results.** Two types of data analyses were performed. The first of these is concerned with the degree to which the subject's prediction came true. As stated earlier, each of the four subjects answered five questions at the beginning of the experiment ("before" rating) and after each of 16 runs ("after" rating). Product moment correlations were computed for these 16 "before-after" observations, and a coefficient of 0.43 ($p < .05$) and of 0.57 ($p < .01$) was obtained.

The second type of data analysis was concerned with the degree to which the results of the simulation runs lead to conclusions which agree with those based upon actual experiences of the subjects in earlier real-life situations. For this, each of the four subjects rated 16 situations and also made runs in these situations. These ratings were indicated by "before" and "after". The data have been subjected to an analysis of variance. Such an analysis will of course show a significant effect of wind direction, windforce, tide or starting point, if the rating before and after taken together offer for the variable in question a sufficiently great difference. Fig. A8 gives an example of the averages corresponding with the question no. 2, which is mentioned in that figure. Other questions had a three-point scale and dealt with the use of the bow rudder, the turn of the vessel into the Hartelkanaal and with other traffic. No significant effects were found.

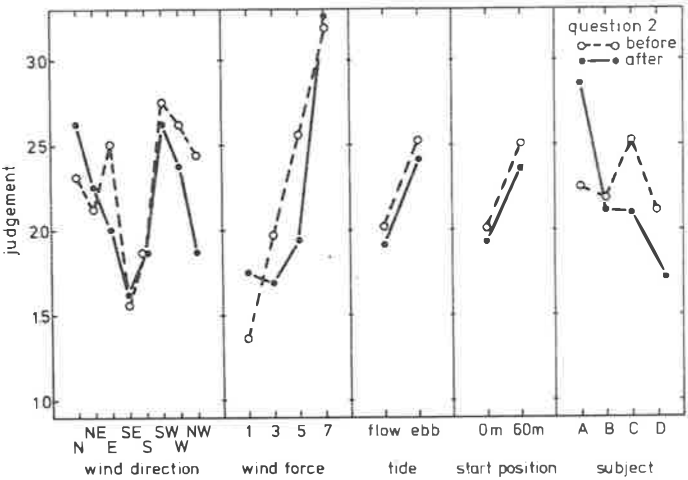


Fig. A8 Effects of wind direction, windforce, tide, starting positions and subjects on the answers to question 2. This question dealt with the passage of the bridge and was formulated as follows:
1 A perfect manoeuvre
2 A good manoeuvre without risk but not optimum
3 The push-tow does not touch the pier but a matter of a risky manoeuvre
4 the push-tow grazes the pier
5 The push-tow ends up on the bank, the wrong side of a pier or straight on a pier.

The possibilities and restrictions of this validation method may be characterized as follows. The method offers possibilities when manoeuvres defined in practice cannot be carried out. Restrictions of the method relate mainly to the unreliability of the ratings. Ratings concerning runs carried out in similar conditions may, for example, differ because a manoeuvre may be one time more successful than another time. Some information with regard to this variability may be obtained from the correlations of the ratings "before", as an inter-judge reliability. This appears to be of the same order as the before/after correlations. The median correlation between subjects amounts to 0.57 and the median before/after correlation to 0.61. This difference is not significant (Mann and Whitney U-test U = 58.5, p < .10). With these results, comparing predictions and simulator runs by means of correlation and by testing on differences, the simulation was considered to be valid.

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## CURRICULUM VITAE

Herke Schuffel werd in 1942 te Hoorn (NH) geboren. Na de HBS-B opleiding te Hoorn, begon hij in 1960 aan de Technische Hogeschool te Delft met de studie Scheepsbouwkunde. In 1968 behaalde hij het ingenieursdiploma en vervulde daarna de militaire dienstplicht. Sinds 1970 werkt hij als wetenschappelijk medewerker bij het Instituut voor Zintuigfysiologie TNO te Soesterberg. Aanvankelijk verrichtte hij daar ergonomisch onderzoek voor de inrichting van operationele ruimten van schepen der Koninklijke Marine. Naderhand breidde het onderzoek zich uit over een breder maritiem ergonomisch terrein. In 1984 werd hij benoemd tot hoofd van de afdeling Technische Menskunde.