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DECISION MAKING IN A DYNAMIC SITUATION: THE EFFECT OF TIME RESTRICTIONS AND UNCERTAINTY

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Drs. J.H. Kerstholt
18 februari 1994, Rapport TM 1994 B-3
TNO Technische Menskunde[1], Soesterberg

MANAGEMENT UITTREKSEL

Informatieverwerking in dynamische situaties onderscheidt zich op een aantal dimensies van beslisgedrag in de meeste in onderzoek gebruikte statische omgevingen. Een belangrijk kenmerk van een dynamische situatie is dat de omgeving voortdurend verandert, autonoom, maar ook door genomen beslissingen. Hierdoor moet de beslisser niet alleen besluiten wat er moet gebeuren om een onwenselijke situatie te verhelpen, maar ook wanneer dit moet gebeuren. In een dynamische omgeving heeft men bovendien de mogelijkheid om gebruik te maken van feedback. Hierdoor kan de beslisser de effecten van genomen beslissingen op de omgeving nagaan en eventueel een ingeslagen koers wijzigen. Vergeleken met een statische taak krijgt tijdsdruk een andere invulling in dynamische taken. Bij een statische taak moet een deadline worden gesteld, terwijl bij dynamische taken tijdsdruk wordt geïnduceerd door de ontwikkelingen van de omgeving, d.w.z. over tijd neemt de kans op een ongewenste consequentie toe.
Om het beslisgedrag in dynamische omgevingen te onderzoeken werd een taak ontwikkeld, die bovengenoemde karakteristieken bevatte. In deze taak moesten proefpersonen het conditieniveau van een atleet volgen, en indien nodig, ook behandelingen geven. Om na te gaan wat er aan de hand was met de atleet kon informatie worden opgevraagd. Het conditieniveau werd in een grafiek weergegeven. De snelheid waarmee het conditieniveau verslechterde bepaalde de tijdsdruk. In voorgaande experimenten werd geconstateerd dat de proefpersonen weliswaar de informatie sneller verwerkten onder tijdsdruk, maar zij pasten hun strategie niet aan. Er werd gewacht tot een bepaald conditieniveau, men vroeg vervolgens informatie op en selecteerde op grond van deze informatie een behandeling. De a priori kans op "false alarms" was echter vrij groot in deze experimenten (.50). In het geval van een "false alarm" daalde het conditieniveau van de atleet zonder dat daar een fysiologische oorzaak voor was die met een behandeling kon worden verholpen. Het conditieniveau herstelde dan ook vanzelf na verloop van tijd.
In het huidige experiment werd nagegaan in hoeverre de a priori kans op "false alarms" en de voorspelbaarheid van het herstel van het conditieniveau in het geval van een false alarm de gekozen beslisstrategie beïnvloedden. Proefpersonen werden in het experiment geconfronteerd met een kans op een "false alarm" van .25, .50 of .75. Bovendien herstelde het conditieniveau zich als het ofwel een waarde van 50 had bereikt, of ergens tussen 0 en 100.
Uit de resultaten blijkt dat als de a priori kans op een "false alarm" toeneemt, proefpersonen langer wachtten voordat ze begonnen met een diagnose, dat zij de informatie langzamer verwerkten, en dat hun prestaties verslechterden. Er werden geen effecten gevonden met betrekking tot de voorspelbaarheid van het herstel van het conditieniveau van de atleet.

[1] Per 1 februari 1994 is de naam Instituut voor Zintuigfysiologie TNO gewijzigd in TNO Technische Menskunde.

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CONTENTS

Report No.: TM 1994 B-3

Title: Decision making in a dynamic situation: the effect of time restrictions and uncertainty

Author: Drs. J.H. Kerstholt

Institute: TNO Institute for Human Factors
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SUMMARY

Information processing in dynamic situations can be distinguished on a number of dimensions from decision making in the normally used static task environments. First, because the environment changes, time is an inherent dimension of the decision making process. Second, strategies can be used that benefit from feedback. Third, time pressure can be defined from the evolving situation itself rather than by some external criterion. Results from previous experiments suggested that even though subjects speeded up information processing, they did not reserve a sufficient amount of time for diagnosis in fast changing task conditions. In the present experiment we investigated whether *a priori* probability of false alarms and predictability of recovery level, in the case of a false alarm, could account for this finding. Subjects were required to monitor the fitness level of an athlete, who was running a race, and to provide treatments whenever necessary. Time horizon was manipulated by the rate at which the athlete's fitness level declined. When the *a priori* probability of false alarms increased, subjects started their diagnosis process at a later point in time, they were slower in processing the information, and their performance decreased. None of these effects were found for the predictability of the athlete's recovery level.

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TNO Technische Menskunde[1]
Soesterberg

Beslisgedrag in een dynamische situatie: Het effect van tijdsdruk en onzekerheid

J.H. Kerstholt

SAMENVATTING

Informatie verwerking in dynamische situaties onderscheidt zich op een aantal dimensies van beslisgedrag in de meeste in onderzoek gebruikte statische omgevingen. In de eerste plaats moet men expliciet rekening houden met tijd, omdat de beslisomgeving constant verandert. In de tweede plaats kunnen strategieën worden gebruikt waarbij rekening wordt gehouden met feedback, en in de derde plaats kan tijdsdruk worden veroorzaakt door de veranderingen in de situatie zelf in plaats van een externe tijdsindicatie. De resultaten van voorgaande experimenten toonden aan dat proefpersonen weliswaar sneller werkten, maar zij reserveerden onvoldoende tijd voor de diagnose in snel veranderende taakomgevingen. De taak hield in dat proefpersonen het conditieniveau van een atleet in de gaten moesten houden en, indien dit nodig was, behandelingen moesten uitvoeren. Tijdsdruk werd gemanipuleerd door de snelheid waarmee het conditieniveau daalde. In het huidige experiment werd onderzocht of de *a priori* kans op een "false alarm" en de voorspelbaarheid van het herstel van het conditieniveau, indien deze wordt veroorzaakt door een "false alarm", voorgaande resultaten kunnen verklaren. Uit de resultaten blijkt dat als de *a priori* kans op een "false alarm" toeneemt, proefpersonen langer wachtten voordat ze begonnen met een diagnose, dat zij de informatie langzamer verwerkten, en dat hun prestaties verslechterden. Deze effecten werden niet gevonden met betrekking tot de voorspelbaarheid van het herstel van het conditieniveau van de atleet.

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1 INTRODUCTION

Even though many decisions are dynamic by nature, for example, diagnosing a patient or finding a fault in a power plant, only a few studies have investigated the cognitive processes underlying dynamic decision making. The main feature of a dynamic situation is its continuous change over time which, compared with static tasks, may have a major impact on the decision making process (Brehmer, 1992; Hammond, 1988; Hogarth, 1981). Several aspects are noteworthy with regard to dynamic decision making.

First, as the decisions are made in real time, the decision maker explicitly has to deal with the time dimension. A process operator, for example, may have a global idea of the state of the system by monitoring process indicators, but in case of a disturbance a diagnosis process has to be started in order to deduce the exact cause. Therefore, the decision maker not only decides what to do or how to do it, but also when to acquire more information on the actual system state or when to make some adjustments.

Second, from a control theoretical point of view a system can only be controlled when the state of the system can be ascertained and when it is possible to affect the state of the system (Brehmer, 1992). For decision making in dynamic environments an important implication of this characteristic is that feedback can be received, which broadens the range of decision strategies that can be used to deal with the decision problem (Hogarth, 1981). Consider, for example, a physician diagnosing a patient. He or she can either take tests in order to deduce the most likely disorder, but he or she may also start with a treatment, e.g. antibiotics, observe its effects and, if necessary, continue with either tests or another treatment. These two strategies were termed "judgment-oriented" and "action-oriented" respectively by Kleinmuntz and Thomas (1987). From their experiments, Kleinmuntz and Thomas concluded that subjects basically used a "judgment-oriented" strategy, even though an "action-oriented" strategy would have resulted in better performance. This finding was supported by previous experiments in which the rate of change of the system was manipulated. Even when there was only a small amount of time for decision making, subjects predominantly used a "judgment-oriented" strategy (Kerstholt, in press; Kerstholt & Willems, submitted).

Third, in dynamic situations time is an intrinsic aspect of the task, related to the development of the situation itself. Thus, if the situation is rapidly changing, and negative consequences increase, more time pressure may be experienced. This contrasts with static environments in which time pressure is induced by an external time criterion, i.e. a deadline (Edland & Svenson, 1993). Consistent findings from these experiments are that deadlines cause subjects to speed up information processing (Ben Zur & Breznitz, 1981; Maule & Mackie, 1990; Payne, Bettman & Johnson, 1988) and that they switch to simpler strategies, with which less information can be requested (Payne, Bettman & Johnson, 1988; Zakay, 1985). However, because dynamic situations offer a different range of behavioural responses a different conclusion on time pressure effects might be found than in static situations. One possibility to save time in dynamic situations is to change the decision strategy from a "judgment-oriented" to an "action-oriented" strategy when time pressure increases: time is saved by the exclusion of an information search phase. Another possibility is to start a diagnosis process immediately after the onset of a disturbance. Such a strategy provides the decision maker with the maximum amount of time for diagnosing, but it increases the risk of interfering with the system in false alarm situations.

In order to investigate decision making in such a dynamic situation an experimental task was developed. In this task, subjects are required to monitor the continuously changing fitness level of an athlete, who is running a race. Information on the global state of the system, the athlete's fitness level, is presented to the subjects by means of a graph on a computer screen. At several points in time the athlete's fitness level may start to decline, and in order to deduce the underlying cause subjects can request information. A decline is either caused by a physiological disorder, in which case the subjects need to apply a treatment in order to prevent the athlete from collapsing, or it starts off spontaneously. A spontaneous decline is termed a false alarm, from which the athletes will recover by themselves.

In previous studies (Kerstholt, in press; Kerstholt & Willems, submitted) we have manipulated the time horizon by the speed with which the athlete's fitness level declined, and observed its effect on decision making behaviour. As far as the timing is concerned we found that subjects did not schedule a fixed amount of time for their decision making process, but rather waited until a fixed fitness level before interfering with the system. More athletes collapsed, however, when the time horizon became more restricted, suggesting that an insufficient amount of time was reserved for diagnosis in the more restricted time conditions. A possible explanation put forward for this finding stressed the relatively high *a priori* probability of false alarms. We argued that subjects waited until a fixed fitness level in order to avoid information requests in a false alarm situation, and intentionally accepted the increased risk of athlete collapse. Furthermore, this strategy could have been encouraged by the fact that in case of false alarms the athlete's fitness level would recover at a value of approximately 45. The predictability of recovery level, in case of false alarms, could have persuaded them to take more risks.
The main purpose of the present experiment is to elaborate on these findings by manipulating both the *a priori* probability of false alarms, and its predictability in terms of recovery level, i.e. a spontaneous recovery may occur at one specific fitness level (50) or at any level between 100 and 0. I predicted that as the probability of false alarms would increase, subjects would later start their decision making process after observing a fitness decline. On the other hand, when the uncertainty would be increased by a less predictable recovery level I predicted that subjects would sooner start their diagnosis process.

2 METHOD

2.1 Subjects

Thirty subjects, all students at the University of Utrecht, participated voluntarily in the experiment. They were paid Dfl 40,- and furthermore had a chance of receiving a bonus, which was given to the best performing subject.

2.2 The experimental task

Subjects were required to imagine that they were the personal attendant of an athlete who was running a race. The fitness level continuously changed over time, and was presented to the subjects on a computer screen by means of a graph (see Figure 1). This information was constantly available to the subjects. The fitness level of the athlete could vary between 100 (optimal fitness level) and 0 (the athlete has collapsed).

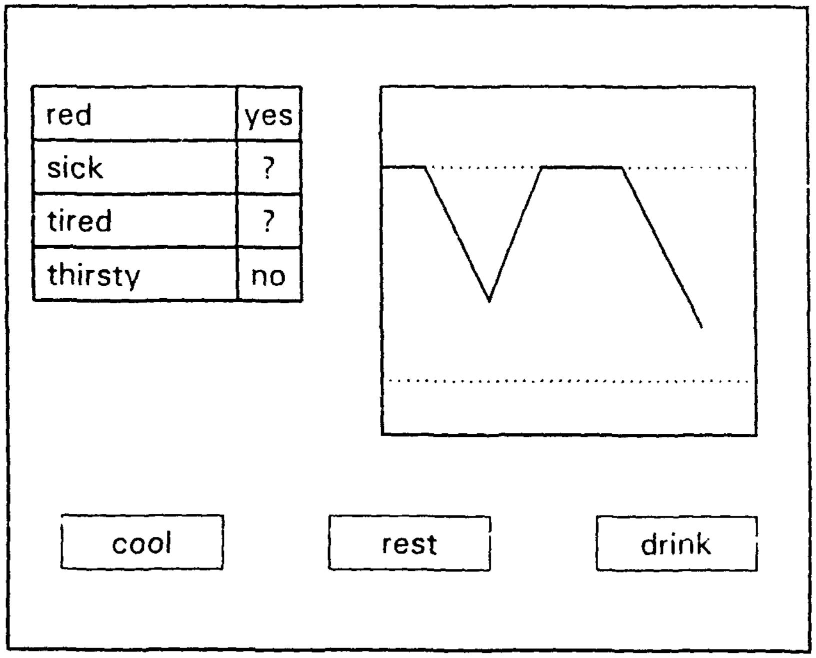

Fig. 1 Example of a computer screen showing the athlete's fitness level, possible symptoms and actions

At several points in time the fitness level would decline, which could be due to four causes with the following *a priori* probabilities (in three different *a priori* probability conditions):

	a priori probability condition 1	2	3
1 temperature problem:	0.05	0.1	0.15
2 circulation problem:	0.05	0.1	0.15
3 metabolism problem:	0.15	0.3	0.45
4 false alarm:	0.75	0.5	0.25

A false alarm means that the fitness level of the athlete declines without any physiological cause, and as a result it will recover spontaneously after some time. The moment at which the fitness level recovered was manipulated: it could either recover at a fitness level of exactly 50, or it could recover at a fitness level randomly selected between 100 and 0. When the decline of the athlete's fitness level was caused by either a temperature, a circulation or a metabolism problem, the fitness level would decline until a fitness level of 0, provided nothing was done by the subject.

A decline was always prompted by a change in one parameter, multiple causes were excluded. Furthermore, the decline evolved linearly. The graph therefore provided information on the onset of a possible disturbance (the fitness level starts to decline) and over time subjects would learn whether the decline was merely a false alarm (the athlete's fitness level spontaneously recovers) or caused by a physiological disturbance.

Each disorder could produce symptoms that provided an indication of the underlying cause. Subjects could request this information. The information requests were served by mouse clicks and the response was either "yes" (the athlete has the symptom) or "no" (the athlete does not have the symptom). The symptoms that could be requested were: red colour, feeling sick, tired, and thirsty. The probabilities of the occurrence of a symptom, given a particular cause were as follows (the probability of the symptom, given other causes is put in brackets):

	temperature	circulation	metabolism	no problem
red colour	0.9 (0.19)	0.1 (0.28)	0.2 (0.29)	0.2 (0.32)
feeling sick	0.2 (0.31)	0.8 (0.24)	0.5 (0.21)	0.1 (0.50)
tired	0.3 (0.52)	0.4 (0.51)	0.6 (0.46)	0.5 (0.49)
thirsty	0.3 (0.43)	0.2 (0.44)	0.8 (0.29)	0.3 (0.54)

If a decline was caused by a physiological disturbance the subjects needed to apply a treatment in order to prevent the athlete from collapsing. For each problem one specific action was needed:

in case of a temperature problem: to cool
in case of a circulation problem: to rest
in case of a metabolism problem: to drink

If the correct treatment was applied the fitness level would be restored, which could be deduced from a change in the curve from a decreasing fitness level to an increasing one.

2.3 Procedure

The experiment was divided into two parts: a training session and the actual experiment. In the training session subjects had to learn the relations between combinations of symptoms and the most probable causes. They were given the information on *a priori* probabilities, on the probabilities of symptoms given the possible causes of the decline, ($p(s_i \mid H_j)$), and on the probabilities of the symptoms given other possible causes of the decline, ($P(s_i \mid -H_j)$). The information on symptom/hypotheses relations were presented in eight bar-plots. Figure 2 shows an example of such a plot for one of the symptoms (red colour). After subjects had studied the bar-plots, they interacted with a computer program that presented them with random combinations of symptoms (for example. "not red, not sick, thirsty and tired"). The subject had to select the most probable cause given the symptoms. After each trial they were given feedback on the accuracy of their diagnosis and in case of an incorrect diagnosis they were also told which one should have been selected. After each run of 10 trials the subject was given feedback on his or her overall score of the run. The general learning criterion was three successive runs comprising two runs that were 100% correct.

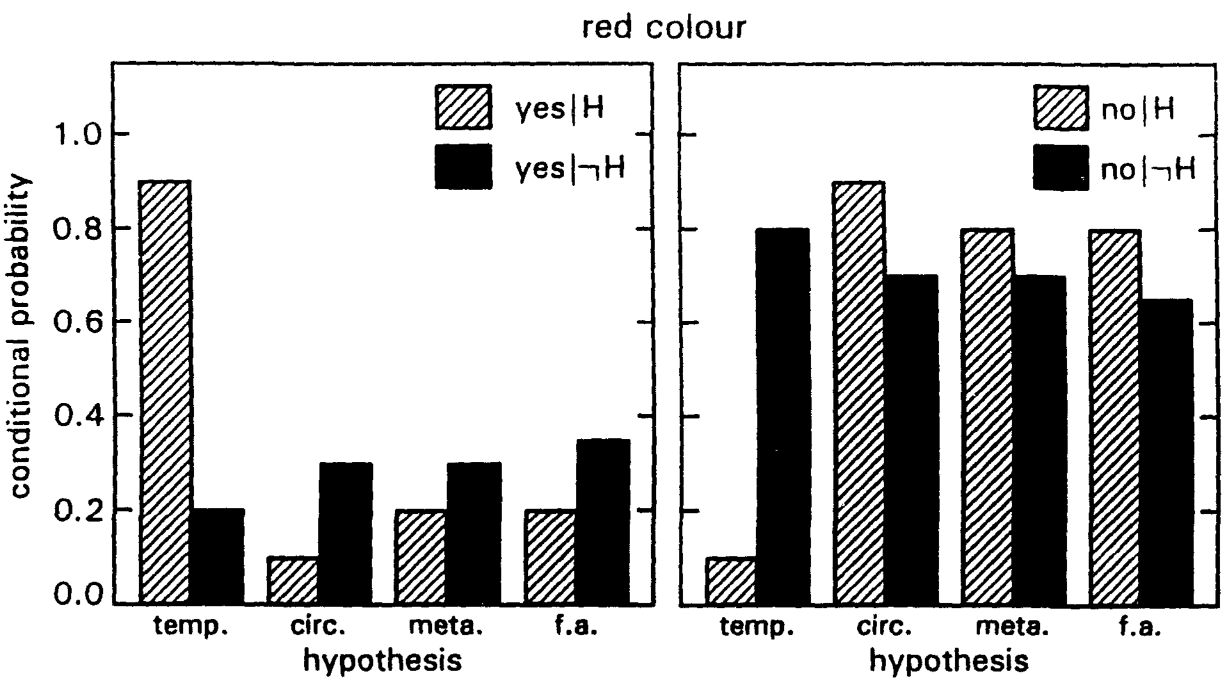

Fig. 2 Information provided to the subjects on the relation between symptoms (in this example red colour) and causes.

The subjects who were assigned to the condition with a probability of false alarms of .75, could have reached the criterion by simply diagnosing that the symptoms were caused by no physiological cause, and would consequently not learn the diagnostic value of the symptoms. These subjects therefore began with the condition where the *a priori* probability of false alarms was .50. After they had reached the criterion in this condition they continued with a false alarm rate of .75, in order to let them experience its effect on the accuracy of the diagnoses.

After learning the relations between symptoms and underlying causes, the subjects continued with the actual experiment.
The subjects were informed on the exact probabilities and they were given practice trials for different time horizon conditions in order to familiarize them with the physical task environment and to determine their decision strategy.
In order to motivate subjects to trade-off information requests and risks on athlete collapses in a thoughtful manner, money was deducted for information requests, wrong treatments and athlete collapses. The subject with the highest overall money level at the end of the experiment received a bonus of Dfl. 50.-.

2.4 Design

A 3*3*2 factorial was used. Time horizon was manipulated by the slope of system decline. It was a within-subjects factor. There were three time conditions: a long time horizon (slope of -4, implying that the athlete's fitness level would decrease in 25 seconds from 100 to 0), a moderate time horizon (slope of -8 or 12.5 seconds) and a short time horizon (slope of -12 or 8.3 seconds). *A priori* probability of a false alarm was either .75, .50 or .25 and was a between-subjects variable. Predictability of recovery level was either high (recovery at a fitness level of 50) or low (recovery at a random fitness level between 100 and 0) and also a between subjects variable. Subjects were randomly assigned to an experimental condition.
The subjects were presented with 30 fitness declines in each time horizon condition. After a correct treatment was applied the fitness level would increase to a value of 100 and the next trial would start.

3 RESULTS

3.1 Training

All subjects were able to learn the relations between symptoms and underlying causes up to the criterion level, even though the subjects in the condition with an *a priori* probability of false alarms of .25 learned the relations faster than the subjects in the condition with an *a priori* probability of .50 (mean number of trials 92 versus 140, $F(1,28)=10.20$, $p<.004$). The learning curves for both groups are plotted in Figure 3. In the last trial block both groups had 97% of the diagnoses correct.

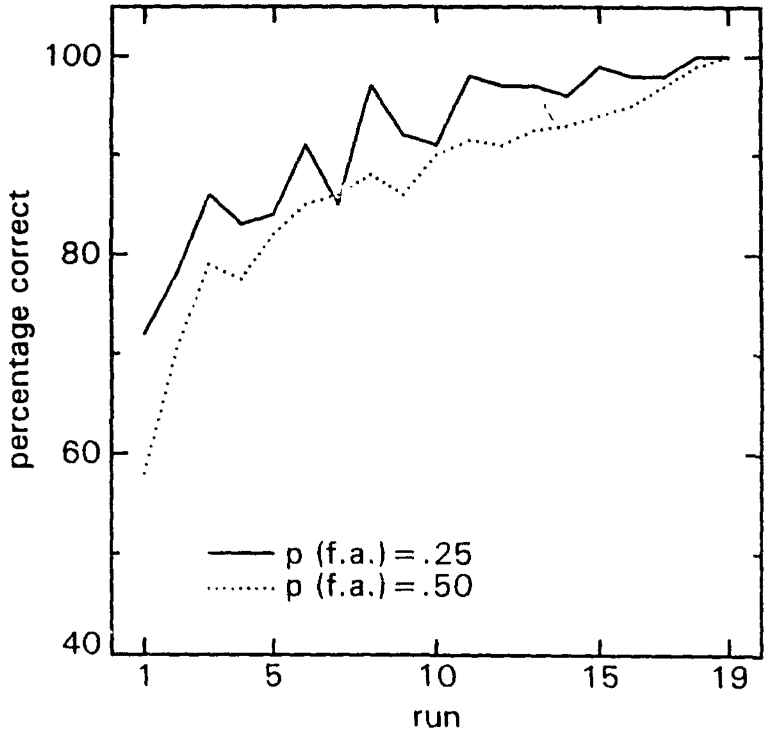

Fig. 3 Learning curves for subjects in the condition with an *a priori* probability of false alarms of .25 and for subjects in the condition with an *a priori* probability of false alarms of .50.

3.2 Experimental data

For all analyses that follow I only selected the "hit" trials, i.e. the trials in which a decline was caused by a physiological disturbance. After observing the onset of a decline subjects cannot deduce whether the decline is caused by a physiological disturbance or by a false alarm, and it can therefore be assumed that they will start the same information processing activities. However, in case of a false alarm these activities will be terminated as soon as an increase in fitness level is observed, which was at a random point in time in half of the experimental conditions.

Time management

The main question of the present experiment concerned the effect of *a priori* probability and predictability of recovery level on the time that subjects would reserve for their diagnosis. For these analyses the relative times were used, i.e. the time subjects waited before they interacted with the system, by either an information request or an action, divided by the total amount of time available. The results show that a decreasing false alarm rate induced subjects to start their information processing activities at an earlier point in time [F(2,26)=4.39, p<.03, see Figure 4]. Put differently, the more subjects expected a false alarm, the longer they waited with information requests or actions.

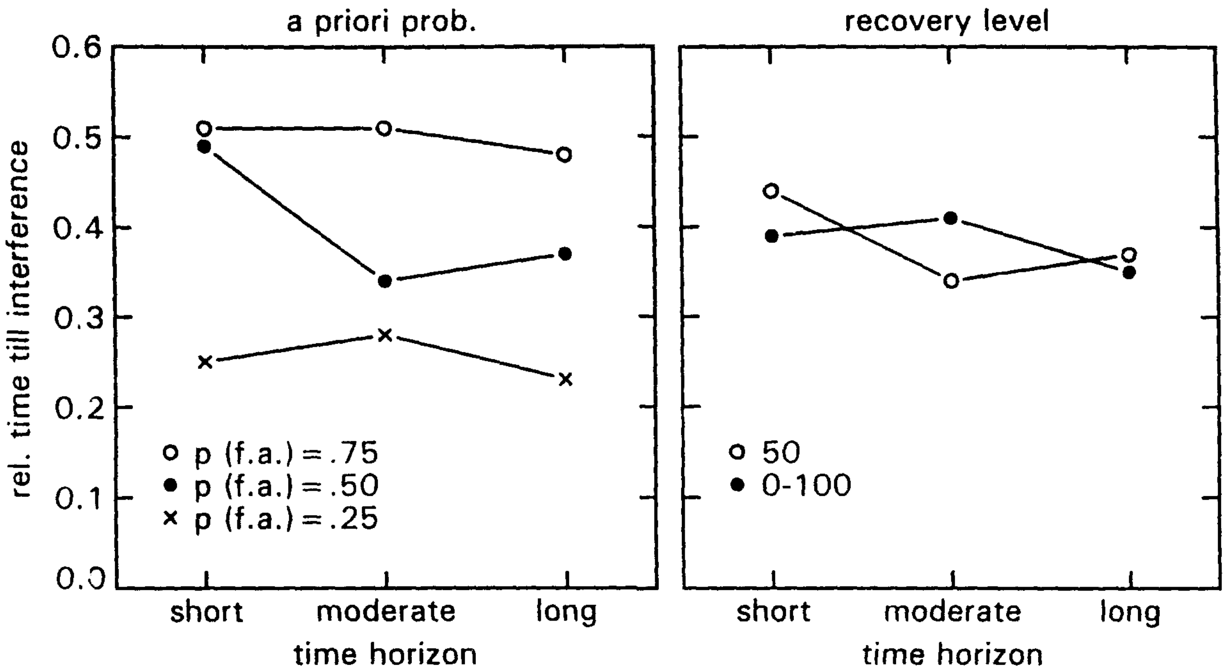

Fig. 4 Relative time till first interference with the athlete for each experimental condition [*a priori* probability of false alarms: .75, .50 or .25 (left panel), recovery level: at a fitness level of 50 or random between 0 and 100 (right panel), time horizon: short, moderate or long (horizontal axis)].

Furthermore, a significant interaction was observed between time horizon and the base rate conditions [F(4,52)=5.00, p<.002]. Subjects waited relatively long when the time horizon was short and the *a priori* probability of a false alarm .50. Predictability of recovery level did not affect the moment of interference (F(1,26)<1). Time horizon only affected the absolute times, meaning that the subjects started to diagnose at an earlier point in time [F(2,52)=91.83; p<.0001] in the fast changing conditions. The relative times remained constant [F(2,52)= 2.02, p>.1, see Figure 4].

Speed of information processing is most directly reflected in the time span between an information request and an immediately succeeding action, during which subjects have to deduce the most probable underlying cause of the decline and to select the appropriate treatment. Subjects were faster when the *a priori* probability of a false alarm decreased [F(2,21)=21.88, p<.0001, see Figure 5]. For this analysis, I only selected the trials in which information was requested. The subjects who consistently used an "action-oriented" strategy were therefore excluded.

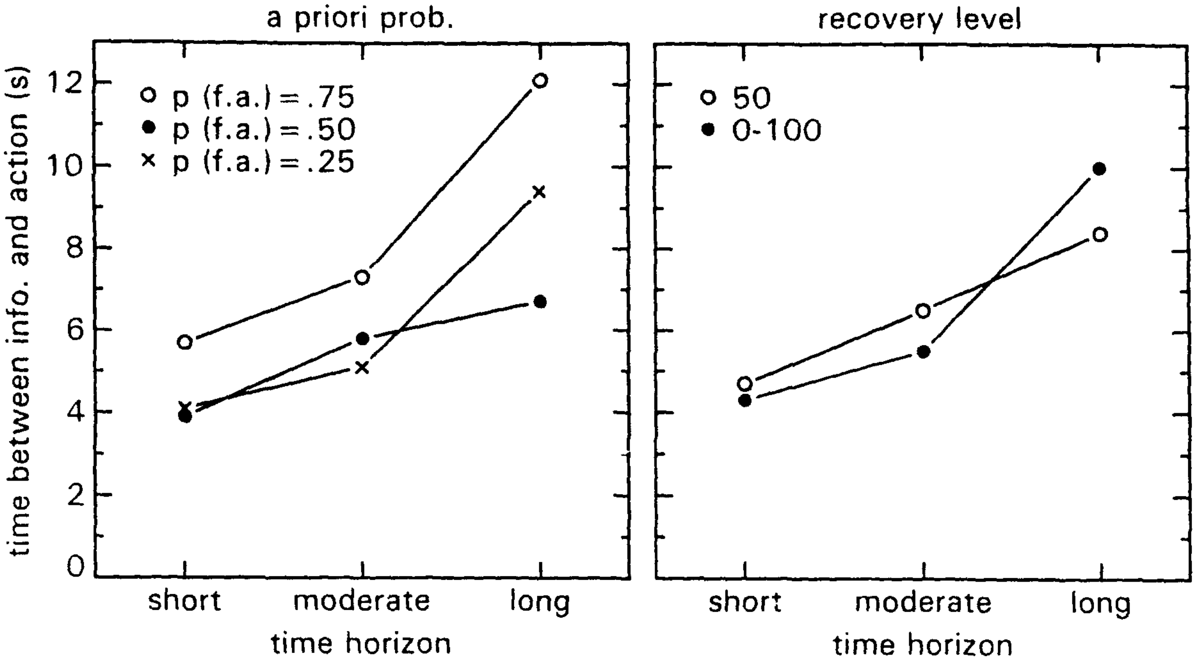

Fig. 5 Time between an information request and a subsequent action for each experimental condition [*a priori* probability of false alarms: .75, .50 or .25 (left panel), recovery level: at a fitness level of 50 or random between 0 and 100 (right panel), time horizon: short, moderate or long (horizontal axis)].

Processing time speeded up as the time horizon became more restricted [$F(2,48) = 61.63$, $p < .0001$, mean times of 9.19, 6.0 and 4.51, respectively]. Furthermore, an interaction was found between time horizon and *a priori* probability [$F(4,48) = 4.65$, $p < .003$, see Figure 5] and time horizon and predictability of recovery level [$F(2,48) = 5.02$, $p < .01$, see Figure 5]. Under the most lenient time horizon subjects are relatively slow when the recovery level is least predictable, and relatively fast in the intermediate *a priori* condition. Overall, predictability of recovery level did not affect processing speed [$F(1,24) < 1$].

Decision strategy

In the introduction a distinction was made between a "judgment-oriented" strategy and an "action-oriented" strategy. The use of either strategy can be deduced from the way subjects react after the onset of a decline. If subjects use a "judgment-oriented" strategy consistently they would first request all information and then apply a treatment. If subjects use an action-oriented strategy, on the other hand, they would immediately apply a treatment after the onset of a decline. Table I shows the proportion of trials in which the onset of a decline was followed by an information request. As can be seen, subjects mostly used a "judgment-oriented" strategy, i.e. they first requested information before applying a treatment. Even though subjects seemed to use an "action-oriented" strategy more often when the *a priori* probability of a false alarm was high, this difference is statistically not significant [$F(2,26)=1.92$, $p>.1$]. Subjects also used the same strategy in the "recovery level" conditions [$F(1,26)<1$] and in the various time horizon conditions [$F(2,52)=1.72$, $p>.1$].

Table I Proportion of trials in which a decline was followed by an information request for each experimental condition (*a priori* probability of false alarms: .75, .50 or .25, recovery level: at a fitness level of 50 or random between 0 and 100, time horizon: short, moderate or long).

		prop. trials
p(f.a.)	.75 .50 .25	.58 .89 .79
recovery level	50 0-100	.79 .72
time horizon	short moderate long	.72 .74 .79

Information requests and actions

Subjects requested the same amount of information in the different *a priori* probability conditions, and in the two recovery level conditions [$F(2,26)<1$ and $F(1,26)<1$]. Subjects requested less information when the time horizon decreased [$F(2,52)=5.43$, $p<.01$, see Table II].
To indicate whether subjects requested the most diagnostic information I calculated the extent to which the various symptoms (S_j) would reduce the uncertainty with regard to the possible hypotheses (H_i). The following formula was used:

$$\sum_{i=1}^{3} \left[(H_i|S_j) * \log_2\left(\frac{1}{(H_i|S_j)}\right) \right]$$

This formula was applied for both the situation where the symptom would be absent and the situation where the symptom would be present. The overall value was attained by weighing the amount of information by the probability of the symptom being respectively absent or present. The uncertainty remaining after knowing the outcome for one symptom was: 1.53 bits for the symptom "red", 1.48 bits for the symptom "sick", 1.56 bits for the symptom "thirsty", and 1.66 bits for

the symptom "tired" (when no symptoms are known the uncertainty is 1.68 bits). Thus, from these data it can be inferred that the symptom "sick" reduces most uncertainty, and it would therefore be rational to request this symptom first.
In order to make the information requests by the subjects comparable with this normative situation I will only evaluate the first information request after the onset of a decline (see Table II).

Table II Proportion of symptoms that were first requested after the onset of a fitness decline, the overall proportion of requested information and proportion of actions for each experimental condition (*a priori* probability of false alarms: .75, .50 or .25, time horizon: short, moderate or long, recovery level: at a fitness level of 50 or random between 0 and 100).

		symptom				prop. info	prop. actions
		red	sick	tired	thirsty		
p(f.a.)	.75	.09	.37	.02	.10	.36	.42
	.50	.02	.56	.16	.17	.45	.47
	.25	.12	.22	0	.42	.46	.46
time horizon	short	.09	.37	.03	.22	.38	.42
	moderate	.08	.40	.08	.19	.42	.46
	long	.07	.38	.08	.28	.47	.50
recovery level	50	.13	.52	.01	.13	.41	.49
	0-100	.03	.24	.11	.30	.43	.50

Not all kinds of symptoms were equally often requested [$F(3,78)=5.03$, $p<.005$]. Subjects mostly requested the symptoms "sick" and "thirsty" (at a proportion of .38 and .23 respectively) and they requested the symptoms "tired" and "red" less often (at a proportion of .06 and .08 respectively). The most often requested symptom corresponds with the symptom reducing most uncertainty (sick). However, even though the symptom "red" would reduce more uncertainty than the symptom "thirst", this symptom was only rarely requested after observing a fitness decline.
Subjects requested a different kind of information when the recovery level became less predictable ($F(3,78)=2.60$, $p=.06$). When subjects exactly knew the recovery level of the athlete, they requested the symptom "sick" and "red" more often and the symptoms "thirst" and "tired" less often. In other words, in this situation subjects request symptoms that reduce more uncertainty about the underlying cause of a fitness decline, than in the condition in which the recovery level cannot be predicted. The kind of information requests did not change over probability conditions [$F(6,78)=1.68$, $p>.1$].

The number of actions that were carried out decreased when the time horizon became more restricted [$F(2,52)=8.01$, $p<.001$], see Table II. Subjects carried out the same number of actions in the "*a priori* probability" conditions [$F(2,26) = 1.18$, $p>.3$] and in the "recovery-level" conditions [$F(2,26)<1$].

Performance

More athletes collapsed when the time horizon became more restricted [$F(2,52) = 17.03$, $p<.0001$], and when the *a priori* probability of a false alarm increased [$F(2,26)=5.55$, $p<.01$, see Table III].

Table III Proportion of athlete collapses, proportion of incorrect treatments and the accuracy of the diagnoses in each experimental condition (time horizon: short, moderate or long, *a priori* probability of false alarms: .75, .50 or .25, recovery level: at a fitness level of 50 or random between 0 and 100).

	time horizon			p(f.a.)			recovery level	
	short	moderate	long	.75	.50	.25	50	0-100
prop. athlete collapses	.29	.19	.10	.31	.17	.10	.19	.20
prop. incorrect treatments	.55	.54	.57	.59	.59	.48	.55	.56
accuracy diagnoses	.30	.31	.29	.53	.25	.12	.30	.30

The accuracy of the actions chosen can be analyzed in two separate ways: the accuracy can be related to the actual state of the athlete and to the knowledge that subjects have of the state of the system, by means of the information requested. The number of incorrect treatments did not differ over the experimental conditions [time: $F(2,52)<1$, *a priori* probability: $F(2,26)=1.25$, $p>.3$, recovery level: $F(1,26)<1$), see Table III].
Second, the action accuracy can be analyzed with respect to the knowledge possessed by the subjects, i.e. given the information they have requested. The diagnoses were worse when the *a priori* probability of a false alarm was high [$F(2,26)=79.29$; $p<.0001$, see Table III]. Diagnosis accuracy did not differ over the "time horizon" and "recovery-level" conditions.

4 DISCUSSION

In previous experiments it was shown that time horizon did not affect the moment subjects would start to interfere with the system, by either requesting information or applying treatments. The present experiment replicated this finding but also showed that the timing was sensitive to the *a priori* probability of false alarms: when the probability of false alarms increased subjects waited longer before they started their diagnosis process.

As a result of this long waiting period more athletes collapsed. However, by waiting longer subjects could avoid costs of information requests in false alarm trials, and they might have accepted the higher risk of an athlete collapse by saving on these costs. Still, even though the timing seems to be a quite adaptive response to the increased false alarm rate, other results can be less easily explained within such a framework: subjects were slower in processing the information and they made less accurate diagnoses given the requested information. These results cannot be explained within a concept emphasising the trade-off of costs, but rather seem to refer to some energetic concept (Sanders, 1983). Possibly, subjects felt bored when the false alarm rate was high, and were less prepared to invest effort into the task. This finding agrees with results from a previous experiment in which we found that less accurate diagnoses were made when subjects had ample time for decision making (Kerstholt & Willems, submitted). Compared with the present "long time horizon" condition, in that experiment the decision period was 8 times longer.

In contrast with the *a priori* probability manipulation, the knowledge of the moment of recovery did not affect the decision process, except for the kind of information requests: from an information theoretical point of view, subjects requested less optimal symptoms when the recovery level was unknown, as when the recovery level was exactly known.

In all previous experiments within the present paradigm we observed that subjects waited until the same fitness level before interfering with the athlete in each time horizon condition, in spite of an increased risk of athlete collapses in the fast changing conditions. One possible explanation for this finding was that subjects want to reduce their uncertainty on whether the decline is caused by a false alarm, and are persuaded to wait until the fitness level that will provide them with this information. In other words, the risks that were taken might have been caused by the specific fitness criterion defined by the experimenter, rather than by a planned acceptance of the risks. However, since the same timing effects were found in the condition with complete uncertainty about the recovery level, the result cannot be ascribed to the predefined criterion level. The results therefore suggest that the timing is induced by a trade-off of costs and risks, rather than by knowledge of the recovery level.

The most dominant strategy over all experimental conditions was "judgment-oriented". This overall preference for a "judgment-oriented" strategy agrees with previous findings (Kerstholt, in press; Kleinmuntz & Thomas, 1987). One possible explanation for using a "judgment-oriented" strategy may be that a "first diagnose, then act" strategy seems to be intuitively better than just trial-and-error. In general, people may find it more rational to request information first, before making system adjustments. Furthermore, in the present experiment the subjects were also trained to base their diagnosis on the actual symptoms. In the training session, subjects were provided with various symptom combinations and they were required to make a diagnosis given this information. Such a training may have cued the subjects to use a "judgment-oriented strategy". Another explanation is that the costs of actions were relatively expensive as compared with the costs of information, in which case the choice of a 'judgment-oriented" strategy could be a rather rational one.

Numerous studies have been devoted to investigate the ability of people to deal with *a priori* probabilities or base rates (see for example Bar-Hillel, 1990). The results from the present study show that subjects were well aware of base rates and took them into consideration in making their decisions. However, subjects who were trained in the condition with a low probability of false alarms (.25), learned the relationships between symptoms and underlying causes sooner than subjects in the condition with a higher probability of false alarms (.50), which may indicate the difficulty to learn to incorporate base-rate information into a decision. As far as the information requests are concerned it was found that subjects often used the symptom that would reduce most uncertainty (i.e. the symptom "sick"). The kind of information requests changed as a function of recovery level which, compared with an information theoretical norm, suggested that subjects selected the symptoms in a less reflective way, when the recovery level was unknown.

To summarize, *a priori* probability of false alarms has major effects on human decision making in dynamic environments. When the *a priori* probability of false alarms increased subjects waited longer before they started to interfere with the athlete. In combination with the marginal effects of the predictability of recovery level it was suggested that the timing of information requests and actions results from a rational trade-off of costs and benefits. Other effects of probability of false alarms however, cannot be explained within such a framework and seem to result from a tendency to invest less effort when the *a priori* probability of false alarms is high. In agreement with previous findings, reductions in time horizon mainly induce subjects to speed up information processing, but they are willing to take more risks on athlete collapses.

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Information processing in dynamic situations can be distinguished on a number of dimensions from decision making in the normally used static task environments. First, because the environment changes, time is an inherent dimension of the decision making process. Second, strategies can be used that benefit from feedback. Third, time pressure can be defined from the evolving situation itself rather than by some external criterion. Results from previous experiments suggested that even though subjects speeded up information processing, they did not reserve a sufficient amount of time for diagnosis in fast changing task conditions. In the present experiment we investigated whether a priori probability of false alarms and predictability of recovery level, in the case of a false alarm, could account for this finding. Subjects were required to monitor the fitness level of an athlete, who was running a race, and to provide treatments whenever necessary. Time horizon was manipulated by the rate at which the athlete's fitness level declined. When the a priori probability of false alarms increased, subjects started their diagnosis process at a later point in time, they were slower in processing the information, and their performance decreased. None of these effects were found for the predictability of the athlete's recovery level.

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