ELSEVIER

Behavioural Brain Research 129 (2002) 51–59

BEHAVIOURAL BRAIN RESEARCH

www.elsevier.com/locate/bbr

Research report

The relation between task history and movement strategy

Marc H.E. de Lussanet *, Jeroen B.J. Smeets, Eli Brenner

Vakgroep Fysiologie, Erasmus Universiteit, Postbus 1738, NL-3000 DR Rotterdam, The Netherlands

Received 12 March 2001; accepted 27 June 2001

Abstract

In the present study, we examine whether subjects hit identical moving targets differently when the task history is different. Twelve subjects each took part in four experimental sessions. Each session consisted of recurring targets that were the same in all sessions, randomly interleaved with context targets that differed per session. We compared the movements that subjects made towards the recurring targets. There were clear influences of the preceding target on the hitting movements within a session, and clear differences between movements towards the same targets between sessions, but the latter differences were not consistently related to the kind of sessions involved. This indicates that influences of task history are limited to the use of information from preceding trials rather than to changes in how information is used (movement strategy). © 2002 Elsevier Science B.V. All rights reserved.

Keywords: Human; Arm movements; Variability; Interception; Hitting; Flexibility; Context; Motor control

1. Introduction

How we move depends on what we want to do: on the task. For example, in a hitting task, the hand's movement speed will depend on the instructions for speed and accuracy. However, the speed of the target and even that of the background on which the target moves will also influence the hand's speed [2,12]. Many studies address how the task and the experimental conditions influence movements. One aspect of the experimental conditions that has received surprisingly little attention is the influence of task history (the preceding trials) on how a task is performed. This will be the focus of the present study.

In many cases, it is conceivable that the task history influences subjects' expectations of the present conditions, and therefore influences which sensory information subjects use—and how—to execute a movement. If task history thus influences how one moves, the choice of other conditions in an experiment will influence a subject's performance in a given condition. In other words, in a given condition subjects may perform differently in different experiments.

The idea that the task history may play a significant role in movement control is of course not new. For example, Smeets and Brenner [12] formulated a model in which an important and functional role was proposed for the task history. In their interception task, the perceived target speed did not directly influence the direction in which subjects started to move, though subjects clearly aimed ahead of moving targets. They proposed that subjects base their prediction of where they will hit a moving target depends on the speed of previous targets. Indeed, the speed of the target in the preceding trial influences hitting movements [3].

The above example clarifies what we mean with influences of task history. It is a difference in performance between trials of which the task and the present conditions are the same, but for which the task or the conditions in the preceding trials differ. We will continue with some more examples. Rossetti and Régnier [11] let subjects point to remembered targets. They found that the distribution of the endpoints of move-

* Corresponding author. Tel.: +31-10-408-7567; fax: +31-10-408-9457.

E-mail address: delussanet@fys.fgg.eur.nl (M.H.E. de Lussanet).

PII: S0166-4328(01)00320-5

ments to one target position was influenced by the distribution of the positions of the target in the other pointing trials. Thus, the endpoints of individual movements to targets at the same position were influenced by the target's position in preceding movements. In another example, the proportion of preceding trials with visual feedback influenced reaction time and grip opening in prehension movements [6].

Sometimes an effect of task history was looked for but was not found. Proteau and Masson [10] did a control experiment to show that there was no influence of task history in their main experiment. They were interested in the influence of unexpectedly moving the background on how subjects move a cursor to a line. In the control experiment the background never moved. Indeed they found no difference between the trials in the control experiment and those in the main experiment in which the background was stationary, even though in the latter the background had sometimes moved in preceding trials.

Fig. 1 gives an example of an influence of task history in a study that addressed the use of size cues in picking up objects. The figure is based on data from an experiment by Gordon et al. [5]. Subjects lifted small and large boxes in random order. The weight of the large ones differed between blocks. The interesting result in the context of task history, is that the weight of the large boxes influenced how the small boxes were lifted, although the small boxes always had the same weight. Grip force was higher for the small boxes when preceding trials included heavy boxes.

An explanation for the subjects' behaviour in three of the studies mentioned above [5,6,11], can be sought in two directions. One explanation is that the subjects changed their movement strategy to cope with the different sets of experimental conditions. In this context, movement strategy is how information concerning the present target is used (and which information). This may be influenced by the variability and the mean of

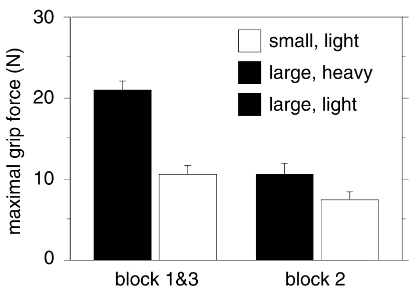

Fig. 1. An example of the influence of task history (based on Table 1 in [5]). Subjects lifted small and large boxes in three consecutive blocks. In block 2, the large boxes had the same weight as the small ones (300 g). In the others, the large boxes were heavier (1200 g). The maximal grip force when lifting the small boxes was lower when the large boxes were light (block 2), than when they were heavy (blocks 1 and 3). Error bars indicate standard errors of the mean.

the relevant information in the preceding trials. For example, when a source of information is constant (when the same condition is presented in two subsequent trials) there is no need to process the information again. As a consequence, the reaction time for a given condition is shorter when the frequency with which that condition occurred in preceding trials is higher [9].

A second, very different explanation could lead to similar results in the studies mentioned before the above example. Subjects may partly have used information from the preceding trials instead of the most recent information (like in [3]). For this second explanation for influences of task history, we can give two more examples. Jaric et al. [7] studied unidirectional movements with an inertial load on the hand, that sometimes unexpectedly differed from the load in the preceding trial. They compared movements for which the preceding 3–6 trials had been made with either the same load or a different one. Jaric et al. found small differences in the velocity profile of these movements. This means that information about the load in the preceding trials had been used to plan the present movement. A second example of the use from preceding trials are anticipatory movements. Anticipatory eye movements are made for example, when in previous trials a target jump occurred (e.g. [8]). These anticipatory eye movements depended on the direction of the jumps on the preceding 3–4 targets. In the same experiment, there was also an effect of the previous trials on the final gaze in the same direction as the anticipatory movements. Naturally, it is very unlikely that the influence on the final direction resulted from a change in movement strategy whereas the anticipatory movements did not.

The two explanations for an influence of task history will lead to effects on different time scales. A change of movement strategy will last longer than a few trials, and should therefore be revealed in differences in the movements for a given condition in different experiments. On the other hand, the use of information from preceding trials is more likely to last just one or a few trials. The studies mentioned above either cannot distinguish between these two explanations, or tested just one of them. The present experiment was designed to find effects in the movement strategy.

We presented different task histories in four separate experimental sessions. Two kinds of targets were identical in all the sessions (recurring targets). The movements toward these targets were analysed. The other kinds of targets differed between the sessions (context targets). They were presented to vary the task history of the recurring targets. Compared to the Reference session, those of the other sessions either contained more variability in the range of target speeds, or included perturbations of either the hand's or the target's position. In order to determine whether subjects hit targets differently with a different task history we compared

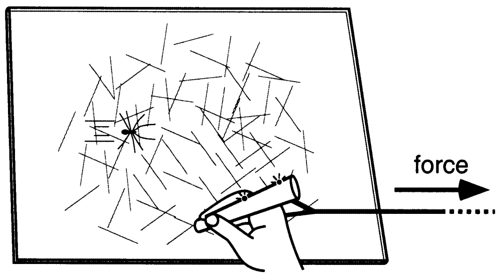

Fig. 2. Experimental set-up. In one of the sessions, a servomotor generated a rightward force on the rod. The hand started 35–45 cm from the screen.

how they hit recurring targets in each session with how they hit the same targets in the Reference session.

It is conceivable that subjects directly control movement speed and curvature of the movement path during fast interceptive movements. It is at least as likely though, that these aspects of the movement emerge from the control of other parameters, such as stiffness and damping [12], or reflex-gains [4]. Different models assume different controlled parameters and therefore will predict different effects of task history on the movement [7]. We chose for a general, model-free approach by analysing various parameters that describe the shape and timing of the movements.

A change of movement strategy can be revealed by comparing trials with recurring targets between the sessions. Within each session the features of the context targets were designed symmetrically around the recurring targets, so that direct influences of the preceding trials would cancel out when comparing between sessions. The latter kind of influences were examined by comparing trials within each session. Thus, we could distinguish between influences of task history that resulted from a change in movement strategy, and those that resulted from the use of information from the preceding trial.

2. Materials and methods

2.1. Apparatus and stimuli

The visual stimulus was as described in [1]. Subjects sat in a darkened room in front of a screen (44 × 36 cm) on which the targets were shown. They were to hit each target with a rod (Fig. 2). The target was an animated spider of realistic shape and natural movements. The screen was tilted 30° backwards (top of the screen farther away from the subject) to make the hitting more comfortable images were presented with a graphic workstation at 120 Hz.

The hitting rod (22-cm long; 1.7-cm diameter) had a soft tip and was held with the tip in the direction of the screen, like one would hold a pencil. The position of the hitting rod was measured at 250 Hz with active infrared markers (Optotrak 3010, Northern Digital, Waterloo, Ontario). The position of the tip of the rod was extrapolated from these markers' positions.

In one of the sessions, an electric servomotor (BBC Brown Boveri, MC23AS) provided a controlled, rightward force on the hand. A 3-m long thread (Twaron ripcord 840 ddex Z6, Akzo Nobel, the Netherlands; non-twined to minimise strain, but treated with hair-spray instead to prevent fray) connected the rod to a 40 cm lever, mounted on the axle of the motor. The force in the thread (and thus on the rod) was measured by a miniature force transducer (Wazau CMDZ, Berlin, Germany; 0–300 N, weight 6 g) at 6 cm from the rod. The force on the rod was regulated with a proportional regulator. The force built up with a time constant of 12 ms and a static friction of 3% at 2.0 N.

2.2. Subjects

Twelve subjects (including the authors) took part in four different experimental sessions on separate days. Later, 12 subjects performed a control experiment; nine of these subjects (including the authors) had also taken part in the main experiment. Apart from the authors, the subjects were naive with respect to the purpose of the experiments.

2.3. Procedure

The experimental sessions lasted ~15 min each. Subjects were to hit moving virtual spiders as quickly as possible after they appeared on the screen. They knew that they would obtain points for each hit: more points for faster hits, and no points for misses. At the end of each session subjects saw their score. Neither before nor after an experimental session were they told what kinds of targets were presented (but the perturbations of the hand in one session and of the target's position in another were clearly noticeable).

Before each trial, if necessary, the subject's hand was guided to the starting range by means of messages on the screen. This starting range was located at a distance of 35–45 cm from the screen. Within 0.5–2.0 s of the subject holding his or her hand stationary within this starting range, the target appeared. A trial ended when the hand reached the screen. The target appeared to be squashed if it was hit, or ran away in a direction opposite to a miss.

2.4. Sessions

The order of the four sessions in the main experiment was counterbalanced across subjects. The control experiment that we carried out later, consisted of three experimental sessions (on 3 different days) which were the same as the Reference session in the main experiment (see below). The nine subjects who had also participated in the main experiment did only two sessions in addition to the one which was the Reference session in the main experiment.

In each session, the targets were presented in four equal blocks of thirty trials (without intervals between the blocks). Within a block, each of six kinds of targets was presented five times, in random order. The first block of 30 trials was excluded from the analysis in order only to analyse the trials in which the task history is clearly defined.

The sessions were designed to present the subjects with specific task histories. To make the results of the sessions comparable, two kinds of targets were presented in each of the sessions (recurring targets), while four other kinds of targets differed between sessions (context targets). The movements toward context targets were not analysed but were necessary to give a specific task history to the trials with a recurring target. The recurring targets moved at a speed of 15 cm/s, and they appeared either 8.5 or 4.5 cm to the left of the hand. We will refer to them as 'left recurring target' and 'right recurring target', respectively.

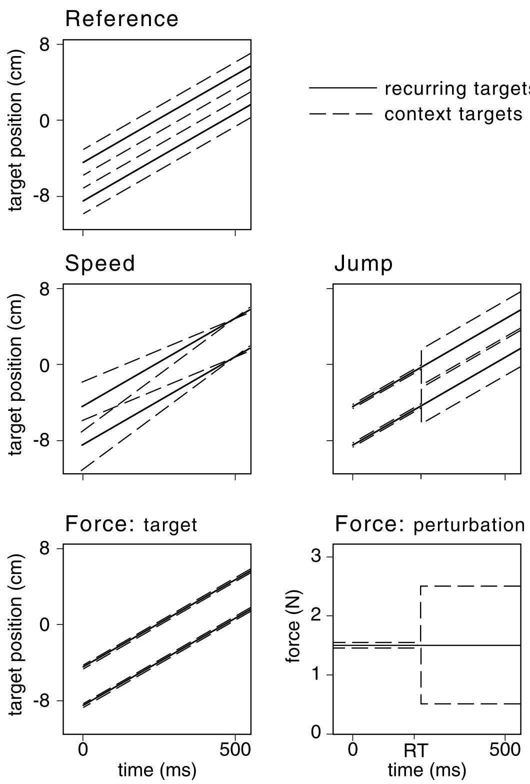

Fig. 3. Characteristics of the four experimental sessions. Continuous lines depict the two kinds of recurring targets; dashed lines represent the context targets. The first four panels give spider position as a function of time (0 cm is the position on the screen opposite to the starting position of the hand). Targets moved at a constant speed until the screen was hit. The 5th panel presents the force development in the Force session: during the context trials there was a sudden pull on or release of the hand when the hand started to move.

Fig. 3 summarises the targets' properties in the four sessions (that we will from now on call by the name above each panel). We will use the results of the Reference session as a reference for the results of the three other sessions. In this session, the context targets appeared at a range of different lateral positions, but they all moved at the same speed (15 cm/s).

In session Speed, the context targets had speeds of 10 and 20 cm/s. In session Jump and session Force, the context trials were perturbed. In session Jump, context targets jumped leftwards or rightwards when the subject's hand started to move. In the session Force, there was a constant force of 1.5 N to the right on the hitting rod. During the context trials, this force suddenly decreased or increased by 1.0 N when the subject's hand started to move. We must keep in mind that in session Force, the pre-load itself could affect the subjects' movements, which of course is not an influence of task history.

2.5. Movement analysis

Of each session, only the 30 recurring targets of the last three blocks (five targets of each kind per block) were analysed. Out of the 1440 hits towards recurring targets (four sessions $\times$ 12 subjects $\times$ 30 trials), 31 were rejected mainly because the markers were invisible to the Optotrak or because the subject was already moving when the target appeared. In the control experiment 13 trials—out of 1080—were rejected for these reasons.

The position in the fore-aft direction (perpendicular to the hitting screen) and in the lateral direction were each numerically low-pass filtered without phase shift (Butterworth 4th order, back and forth in time, effective cut off frequency: 20 Hz). Movement initiation was defined as the moment at which the hand's velocity towards the screen exceeded 0.2 m/s. For this, the velocity was low-pass filtered (effective cut off frequency: 10 Hz). The exact position and the time of hitting the screen were extrapolated from the last three samples before the screen was reached. The timing of the perturbations (sessions Jump and Force) was obviously computed on-line, and therefore on the unfiltered data.

Fig. 4 shows the movement parameters that we analysed. The reaction time (RT) is the time from the spider's appearance until the hand started to move. The movement time (MT) is the time from when the hand started to move until the screen was hit. V_{max} is the maximal tangential velocity. The rTV_{max} is the time from RT until V_{max}, divided by the MT.

The initial movement direction (IMDirection) is the angle between the direction perpendicular to the screen,

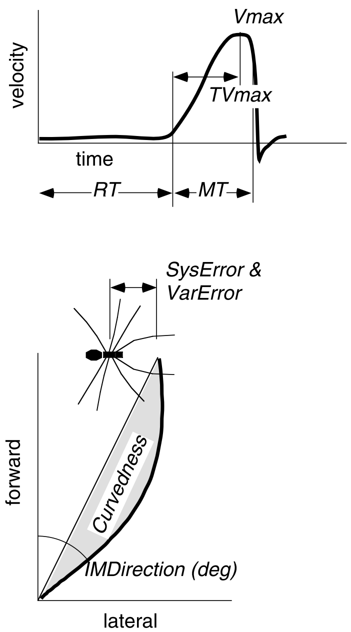

Fig. 4. The movement parameters. In the analyses we used $rTV_{max} = 100*TV_{max}/MT$.

and the line through the hand's starting position and the hand's position 5 cm closer to the screen. The Curvedness is the path's average deviation from a straight line between start and end (rightward is positive Curvedness). The systematic error (SysError) is the average lateral difference between the centre of the rod and that of the spider when the screen was hit. The variable error (VarError) is the standard deviation of this difference. We deliberately chose to include a relatively large number of movement parameters, although this implies that some parameters will be dependent (see Section 3).

The two kinds of recurring targets differed only in position. Nevertheless, we cannot simply average the movements towards the two because there could be both mirrored and congruent influences of task history. With congruent we mean that an influence of task history is in the same direction for both kinds of targets, so that the effect remains visible when the movement parameter is averaged over both kinds of recurring targets. This would for instance be the case if the MT would decrease in sessions in which the hand was sometimes unexpectedly pulled away in preceding trials. A mirror effect is revealed from the difference between the values for a movement parameter in the two kinds of recurring targets. Mirror effects of task history may for example be expected if subjects postponed the use of visual information about the target if it sometimes unexpectedly jumped. In that case, a tendency to start moving straight ahead will increase the IMDirection and the Curvedness for the left recurring target and decrease them for the right ones.

3. Statistical analyses

3.1. Consistent changes

We first tested how each task history altered hits toward recurring targets (compared to the task history in the Reference session). We averaged the movement parameters for each kind of recurring target, subject and session (15 trials per average). We used paired t-tests to test for congruent- and mirror effects (12 pairs: one for each subject). In each test we compared the influence of a given task history with that in the Reference session. In this way, 48 t-tests were needed (three task histories, eight variables, two [congruent or mirror] effects).

This is a considerable number of t-tests, so we need to determine whether the number of statistically significant results that we find is above the number that one would expect from chance. As a first approximation, this number follows from the threshold used ($\alpha = 0.05$). Thus, one expects 5% statistically significant outcomes, even if the task history had no effect whatsoever. However, this is only an approximation because, as we already mentioned, some movement parameters and the related t-tests were dependent. We therefore did the two following controls to estimate the number statistically significant results that we can attribute to chance.

First, we carried out a control experiment in which 12 subjects did the Reference session three times. As the three sessions of this control experiment were of the same type, the number of significant outcomes in the comparison between them is not related to task history. We analysed this experiment 100 times, each time assigning each subject's three control sessions to three arbitrary groups (by this eliminating possible order effects). The same t-tests as described above were carried out between each of the three arbitrary groups of control sessions. From the distribution of the number of significant results in each of the 100 analyses we estimated the 95% limit for the number of chance-based significant results. If the proportion of significant results in our main experiment is larger than this limit, we will consider this as strong evidence for there being an influence of task history.

A second estimate for the limit to the number of chance based statistically significant results was obtained by randomly dividing the sessions from the main experiment into four arbitrary groups in the same manner as we did with the control sessions. We also did this 100 times and computed the 95% limit for the number of significant results that can be attributed to chance.

3.2. Inconsistent changes

Apart from the above question of whether the task history had a consistent effect across subjects, we also calculated how many within-subject changes there were between sessions. This gave us a measure of the variability that was not related to the task history across subjects. For each subject we compared the hits towards recurring targets of each session with those of the same subject's Reference. Unpaired t-tests were used ($\alpha = 0.05$). For each task history, 168 t-tests were carried out (12 subjects, seven variables, two [congruent or mirror] effects). This measure was not applicable for the VarError, which is not defined for individual trials.

3.3. Order related changes

We tried to minimise possible effects related to the order (like learning and fatigue) on our results in two ways. Firstly, the order of performing the kinds of sessions was counterbalanced across the subjects. Secondly, the trials from the first quarter of each experimental session were not analysed. To estimate how much variability was caused by order effects, we estimated the effects of order both within- and between sessions. The kind of session was ignored. For the within session variability we split the 30 analysed trials within each experimental session into the first 15 trials and the last 15 trials. Paired t-tests were performed on the averages of 15 trials. A possible influence of the order of presentation was examined with 56 tests (four sessions, seven variables, two [congruent or mirror] effects).

To find out whether variability between sessions was caused by systematic differences between earlier and later performed sessions, we used another set of paired t-tests. These tests were calculated on the four sessions by the order in which they were executed (so ignoring the kind of session). There were six possible between-session comparisons, eight variables (two [congruent or mirror] effects = 96 tests).

3.4. Influence of the preceding trial

We examined the effects of using information from previous trials, by testing the influence that the preceding trial had on the hitting movements. This was done for sessions Speed, Jump and Force. In each of these sessions we distinguished three groups of preceding targets. In session Speed the three groups were: '10', '15' and '20 cm/s', in session Jump: 'no jump', 'left jump' and 'right jump' and in session Force: 'no change', 'pull' and 'release'. We averaged the movement parameters for each kind of recurring target and each preceding group (six averages for each subject in each session). The means were calculated from five trials on average. This number was variable because the targets appeared in random order.

The subsequent tests that we used were very similar to those used in the analysis of the consistent changes. We used paired t-tests to test for congruent and mirror effects (12 pairs: one for each subject). Each t-test compared the values for two groups of preceding targets. In session Speed, we compared the groups of preceding trials '10 cm/s' and '20 cm/s'. In session Jump we compared groups 'left jump' and 'right jump', and in session Force we compared groups 'release' and 'pull'. In this way, 42 paired t-tests were needed (three task histories, seven variables, two [congruent or mirror] effects). These were the groups for which we expected the largest effects (based on the literature cited in Section 1). These were also the comparisons that would cancel out in the test for consistent changes between the sessions.

We estimated the number of chance based statistically significant results in the same manner as before. We repeated the analysis 45 times, with a randomly assigned group number to each of the analysed trials with recurring targets. From the distribution of the number of significant effects we estimated the 95% limit. If the number of significant results in the experiment is larger than this limit, we will consider this as strong evidence for influences of the preceding trial.

4. Results

4.1. Consistent changes

Fig. 5 shows the average of and the difference between the values for the two kinds of recurring targets for the eight movement parameters. Only two of the 48 t-tests evaluating the consistency across subjects were statistically significant. We estimated the number of chance-based significant effects from the randomised main experiment and from the randomised control experiment. In both cases, 95% of the randomised tests contained not $> 7.5\%$ significant effects. This means, that the number of statistically significant comparisons in the main experiment would have had to be $> 7.5\% * 48 = 3.6$ to attribute any effect to task history. Thus there was no indication of consistent influences of task history across sessions.

4.2. Inconsistent changes

The reason why there was no consistent influence of the task history on the sessions, could be that the subjects did not change their movements between sessions at all. The t-tests evaluating the inconsistent differences between sessions showed that this was not so. In the main experiment, 49% of the tests was statistically significant (51% in the control experiment). Fig. 6 shows the number of significantly different individual comparisons for the various movement parameters. Fig. 7 shows the same data averaged over the three sessions and seven parameters, for the nine subjects that participated in both the main experiment and the control experiment. There are of course differences between the parameters and between the subjects, but a large number of differences between sessions is a consistent feature of all parameters and all subjects in both experiments. The similarity between the number of significant changes for the main experiment and that for the control experiment confirms that the differences are not related to differences in task history.

4.3. Order effects within and between sessions

The order of the sessions was counterbalanced across subjects to prevent order effects (learning, fatigue) from being interpreted as effects of task history. However, possible order effects may have masked the influences of task history. Indeed we did find some order effects, but the proportion of statistically significant tests was small. From the tests on the first and second half of the sessions 8.9% was statistically significant. It is thus possible that there were some within-session order-effects. From the tests comparing earlier and later sessions 6.3% were statistically significant. For the latter test we can use the same estimate for the maximal percentage of chance-based effects as in the test for the

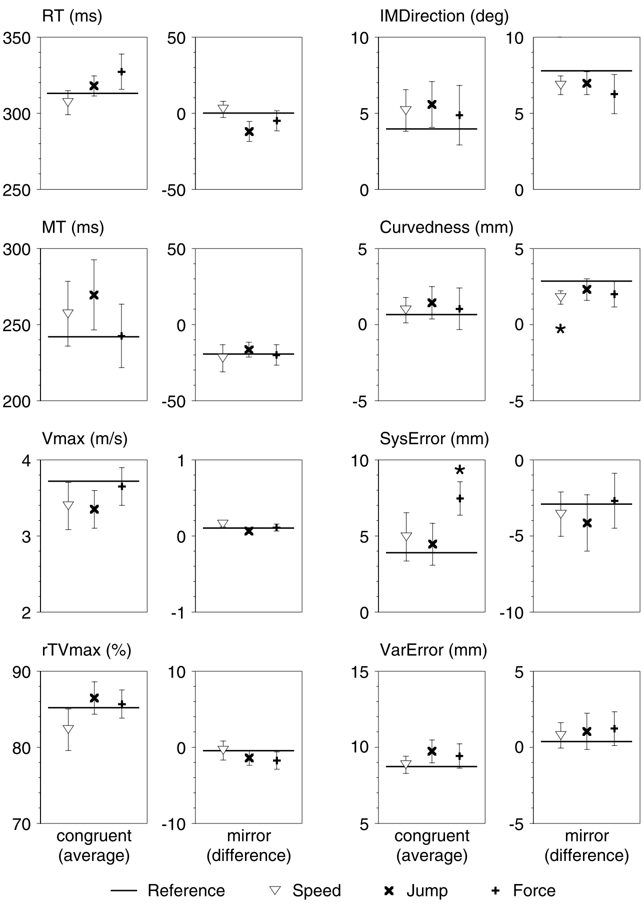

Fig. 5. Consistent changes: results for the hits towards recurring targets. Congruent: Average over the values for the left and right recurring targets. Mirror: Difference between the values for the right and left recurring targets. The asterisks (*) indicate values that differ significantly from the Reference ($\alpha = 0.05$; paired t-test; significant in Speed: Curvedness and in Force: SysError). Bars are inter-subject standard errors of the difference from the Reference.

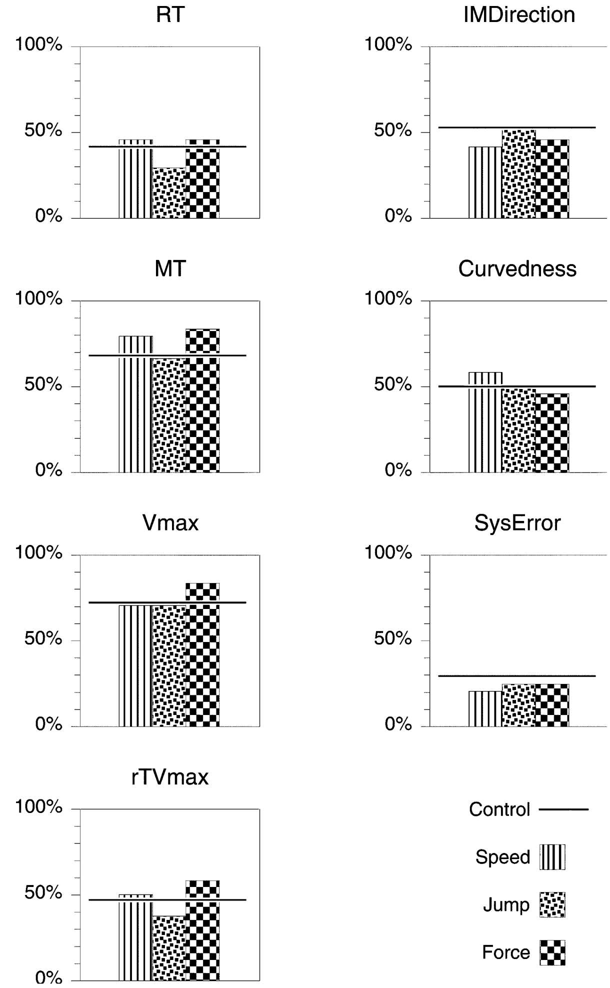

Fig. 6. Percentage of significant changes between sessions ('inconsistent changes') for individual subjects (unpaired t-tests; $\alpha = 0.05$). The measure was not applied to the VarError, as it is not defined for individual trials. Bars: comparisons between the Reference session and the three other sessions in the main experiment. Horizontal lines: comparisons between the sessions in the control experiment.

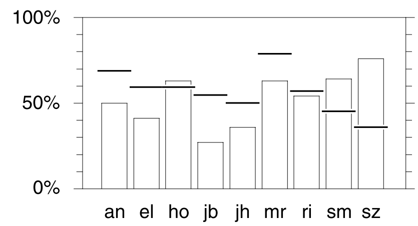

Fig. 7. Percentage significant changes between sessions ('inconsistent changes') for the nine subjects that participated in both the main experiment and the control experiment (100% = 42 tests). Bars: main experiment. Horizontal lines: control experiment.

Table 1
Influences of the preceding trial

Variable	Speed		Jump		Force	
	Difference	P	Difference	P	Difference	P
RT (ms)	–	–	–	–	–	–
MT (ms)	–	–	–	–	–	–
rTV_{max} (%)	–	–	–	–	–	–
V_{max} (m/s)	–	–	–	–	–	–
IMDirection (°)	–	–	2.5	0.03	–	–
Curvedness (cm)	0.14	0.04	0.16	0.01	−0.21	0.02
SysError (cm)	–	–	0.43	0.04	−0.38	0.03

There were only significant congruent effects. The average size of the effect (difference) and the P-values are given for the significant effects. Differences refer to '20–10 cm/s' (session Speed), 'right jump'–'left jump' (session Jump) and 'pull'–'release' (session Force), respectively.

consistent changes, i.e. 7.5%. This means that we can conclude that there were no between-session order effects.

4.4. Influences of the preceding trial

In the above we did not find any proof of consistent task history related changes between the sessions in fast hitting movements. However, from the literature cited in the Introduction, it is clear that influences from the preceding trial should be present in our data. Table 1 summarises the results of this analysis. Out of 42 t-tests, six were statistically significant (14%). We estimated the number of chance-based significant effects from the randomised experimental sessions. A total of 95% of these randomised tests contained 11% or fewer significant effects. We conclude that there were influences of the preceding trial.

5. Discussion

We can summarise the results as follows. There were differences between sessions in how subjects moved, but these differences were not related to the differences in task history between the sessions. The only influences of task history that we did find were related to the kind of the preceding target. This means that we only found evidence for the use of information form preceding trials and not for the subjects changing their movement strategy as a result of the task history.

Inherent to our method of looking for influences of the task history in a general way (i.e. without a hypothesis for exactly which effects one expects) it is unlikely to find an influence in the case when there is just one effect. This is even so if this effect would be very large. Fig. 5 shows however that it is unlikely that there was a single large effect of a consistent influence of task history across sessions in our data. The smaller of the two statistically significant effects was a mirror-effect on the Curvedness in session Speed, while the other was a congruent effect in session Force for the SysError. The magnitude of the first effect hardly differs from the non-significant effects in session Jump and in Session Force, and is therefore unlikely to be more than just statistically significant. The latter effect differs in magnitude clearly from that in session Speed and session Jump, but it is the kind of effect that we expected as a result of the constant pre-load on the hand. It therefore cannot be regarded as an influence of the task history either.

There were many changes in the way the subjects moved in different sessions that were inconsistent across subjects (Fig. 6). One could argue that two groups of subjects possibly each did change their movement strategy in a consistent way when these two strategies cancelled out each other's effects. In that case however, one would expect more inconsistent changes in the main experiment than in the control experiment (of which the sessions were the same). The similarity between the number of inconsistent changes between sessions (Figs. 6 and 7) shows that it was not the case.

The number of influences from the preceding trial that we found may seem little. The reason for this is that the test for influences of the preceding trial had less power than the test for consistent changes between the sessions for two reasons. Firstly, the means that were used in the latter test, were calculated from fewer trials (five instead of 15) and this number varied due to the random order of the trials within a session. In addition, the influences of the preceding trials may last a little longer than just the preceding trial [8], which introduces additional variability. This means that the test for the preceding trial may have underestimated the number of effects. This strengthens our conclusion that there were only influences from the preceding trial, which are not related to changes in movement strategy but only to the use of preceding information.

In contrast to the possible underestimation of the effects from the preceding trial, there is no reason to believe that the number of effects in the comparison for consistent changes between the session types was underestimated. Individual subjects did have many inconsistent changes between the sessions. In addition, we did not find order effects between sessions that could have masked effects of the task history. Therefore, if part of these many changes had been related to consistent influences of the task history, they should have resulted in effects in the test for consistent between-session changes.

What is new in our study is that we were able to distinguish within the same experiment between changes that were related to changes in movement strategy and changes that were due to the use of information from preceding trials. The effects that we found were related to the use of information from the preceding trials. However, the influence of task history in the reaction time study by Miller [9] showed that task history can affect subjects' movement strategy. The effect that Miller found on the RT was 11 ms. This is about the same as the effect in the RT in session Force (compare Fig. 5), but here it was not significant. Van Donkelaar et al. [13] and Brouwer et al. [2] both did experiments in which targets of different speed had to be intercepted. In both studies these targets were presented either in random order (unpredictable condition) or in clusters in which all targets were of the same speed (predictable condition). In Van Donkelaar et al. the RT was significantly longer in the predictable condition whereas in Brouwer et al., it was not. This discrepancy points in the same direction that our study does: that effects of task history that can be related to differences in movement strategy are very small if present at all. This is in contrast with influences of the preceding trial.

Acknowledgements

This research was conducted while the first author was supported by a grant (575-23-002) of the Foundation for Behavioural and Educational Sciences of The Netherlands Organisation for Scientific Research (NWO). We thank Dr C. J. Erkelens, who kindly lent us the electric motor.

References

[1] Brenner E, Smeets JBJ, de Lussanet MHE. Hitting moving targets: continuous control of the acceleration of the hand on the basis of the target's velocity. Exp Brain Res 1998;122:467–74.
[2] Brouwer A-M, Brenner E, Smeets JBJ. Hitting moving targets: the dependency of hand velocity on the speed of the target. Exp Brain Res 2000;133:242–8.
[3] de Lussanet MHE, Smeets JBJ, Brenner E. The effect of expectations on hitting moving targets: influence of the preceding target's speed. Exp Brain Res 2001;137:246–8.
[4] Flanagan JR, Ostry DJ, Feldman AG. Control of trajectory modifications in target-directed reaching. J Motor Behavior 1993;25:140–52.
[5] Gordon AM, Forssberg H, Johansson RS, Westling G. Integration of sensory information during the programming of precision grip: comments on the contributions of size cues. Exp Brain Res 1991;85:226–9.
[6] Jakobson LS, Goodale MA. Factors affecting higher-order movement planning, a kinematic analysis of human prehension. Exp Brain Res 1991;86:199–208.
[7] Jaric S, Milanovic S, Blesic S, Latash ML. Changes in movement kinematics during single-joint movements against expectedly and unexpectedly changed inertial loads. Hum Movement Sci 1999;18:49–66.
[8] Kowler E, Martins AJ, Pavel M. The effect of expectations on slow oculomotor control-IV. Anticipatory smooth eye movements depend on prior target motions. Vision Res 1984;24:197–210.
[9] Miller J. Channel interaction and the redundant-targets effect in bimodal divided attention. J Exp Psych: Hum Perc Perf 1991;17:160–9.
[10] Proteau L, Masson G. Visual perception modifies goal-directed movement control: Supporting evidence from a visual perturbation paradigm. Q J Exp Psych A-Hum Exp Psych 1997;50A:726–41.
[11] Rossetti Y, Régnier C. Representations in action: pointing to a target with various representations. In: Bardy BG, Bootsma RJ, Guiard Y, editors. Studies in perception and action III. Lawrence Erlbaum Associates, 1995. p. 233–236.
[12] Smeets JBJ, Brenner E. Perception and action are based on the same visual information: Distinction between position and velocity. J Exp Psych: Hum Perc Perf 1995;27:77–88.
[13] van Donkelaar P, Lee RG, Gellman RS. Control strategies in directing the hand to moving targets. Exp Brain Res 1992;91:151–61.