Mental rehearsal to enhance navigation learning.

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Abstract

In an effort to test mental rehearsal as an energy efficient way to learn spatial navigation tasks, a maze navigation simulation was constructed. A robot driven by a single layer feed forward neural network had to find his way from its starting location to a target location. The task was learned using mental and physical rehearsal and learned by using only physical rehearsal. Performance was compared between trials with and trials without the use of mental rehearsal. As a result we found that mental rehearsal has a slightly positive effect on performance measure of the robot in the maze navigation task.

1 Introduction

This paper will attempt to find out if mental rehearsal could prove useful for enhancing the performance of an artificial entity training a spatial navigation task, i.e. a robot in a maze.

1.1 Mental rehearsal

Using mental rehearsal means practicing a (partially physical)task using only the mind. Mental rehearsal is a learning function practiced by humans and is applicable for enhancing both cognitive and motor skills. A study by Feltz and Landers [3] reviewing multiple studies on the effect of mental rehearsal shows that mental rehearsal on average increases the performance by 5% regardless of the task. The same study shows that mental rehearsal is more effective in cognitive tasks rather than in motor skill or strength tasks. Jeannerod [5] shows that: “the process of motor representation, normally a non-conscious process, can be accessed consciously under certain conditions: a motor image is a conscious motor representation. According to this definition, motor images are endowed with the same properties as those of the (corresponding) motor representation, that is, they have the same functional relationship to the imagined or represented movement and the same causal role in the generation of this movement”. Knowing this it can be conclude that motor imagery and motor actions at least use partially the same neural patterns therefor strengthening the neural patterns of motor imagery, at least partially strengthens the neural patterns of motor actions.

1.2 Potential advantages and disadvantages of mental rehearsal for an artificial agent

There are two big advantages of mental rehearsal over physical rehearsal:

1. Lack of physical movement avoids physical perils like vessel damage.
2. Imagined movement uses less energy than physical movement.
There are also two big disadvantages of mental rehearsal compared to physical rehearsal:

1. The learning process of mental rehearsal is slower than the learning process of physical rehearsal.
2. With mental rehearsal there is a chance to learn the wrong behavior because the conditions of the task that has to be solved in mental rehearsal are partially based on speculation.

Reducing energy cost and negating the risk of physical damage can be very useful in situations where the robot cannot easily charge itself up or repair/replace itself. An example is the Mars Lander, as documented by Duwanye et al. [1].

1.3 Research question

In order to know if mental rehearsal will enhance the performance of an artificial entity the following questions have to be answered.

1. How does mental rehearsal influence the performance of the robot in the maze navigation task?
   1.1 How does the performance level of a robot influence the effect of mental rehearsal on the performance measure of that artificial entity?
   1.2 Is the effect of mental rehearsal dependant on the complexity of the task?
   1.3 Is the effect of mental rehearsal dependant on knowledge of the artificial entity about the task?
   1.4 Will the use of mental rehearsal increase the energy efficiency of the learning process of a robot?

2. Can mental rehearsal be used to lower the risk of damage during the learning process of a robot?

1.4 Expectations based on human mental rehearsal

We expect to find the following results based on the knowledge of mental rehearsal in humans:

1. We expect an improvement in the pathfinding performance when using mental rehearsal to train the pathfinding.
2. We expect that there is a certain performance level needed, in order for the mental rehearsal function to have any effect.
3. We expect that the positive effect of mental rehearsal will increase as the performance of the robot increases. The better the robot already performs in path finding, the more effect the mental rehearsal will have.
2 Methods

In order to test if using mental rehearsal is an efficient way to train a spatial navigation task; a maze navigation task was created that had to be solved by a single layer feedforward neural network, using mental rehearsal. A maze navigation task simulation was set up where the neural network guided a robot from the starting location to the target location. The neural network was trained to follow the shortest path from his current location to the target location. The shortest path was calculated using Dijkstra’s shortest path algorithm [2].

2.1 Maze

The maze is a two dimensional area of equal height \( N_y \) and width \( N_x \). The maze is divided into \( N_x \times N_y \) squares of equal size. In the simulation there are two versions of the maze: The maze as it is drawn by the simulation (the physical maze) and the representation of the robot about the layout of the maze (the mental maze).

2.1.1 Physical maze

The physical maze represents the physical environment of the robot (reality). In the physical maze a square can have one of two states:

1. Wall
2. Empty

The starting location and the target location are always empty. Because the robot is not allowed to move out of the maze, it will experience the edges of the maze as walls. The physical maze is drawn in the beginning of the experiment and remains constant during the entire experiment. When the robot is in physical rehearsal it moves through the physical maze.

2.1.2 Mental maze

The mental maze is the robot’s representation about the layout of the maze (robot’s interpretation of reality). The robot constructs the mental maze every time it receives new data about the physical maze and every time the robot starts his mental rehearsal. The mental maze is built out of two sections:

1. The squares the robot has already explored in the physical maze.
2. The squares that are unknown to the robot.

All the squares of the physical maze and the robot’s knowledge about them is stored in the “Known Squares Database” (KSD). The KSD is a grid of coordinates of the physical maze. Each point in the grid can have three states:

1. Empty
2. Wall
3. Unknown

At the start of the experiment, all the values in the KSD are Unknown except the starting location and the target location: These two locations are set to Empty. Whenever a robot physically walks into a square that is Unknown to it, the newly found value of this square is added to the KSD. The robot constructs a mental map by taking all the coordinates from the KSD that are not Unknown and assigning the values of those coordinates to the same coordinates in the mental maze. The rest of the maze, which is Unknown to the robot, is filled with squares by a square generation algorithm. This algorithm generates a value for each unknown square based on the known values in the KSD. In order to get the value, the robot first calculates \( P_{\text{empty}} \), the chance that a square in the maze has the Wall state, by dividing the amount of known empty squares by the total amount of known squares. Each Unknown square has \( P_{\text{empty}} \) chance to become Empty and \( 1 - P_{\text{empty}} \) chance to become Wall. When the mental maze is finished, the robot checks if there is a path from the robot to the target location using Dijkstra’s shortest path algorithm [2]. If there is no path from the starting to the target location, the robot deletes his mental maze and creates a new one, until a mental maze is created that contains a path to the target location. As the known section of the maze grows through exploration, the mental maze of the robot becomes more and more similar to the physical maze.

2.1.3 Test mazes

The following three physical mazes have been used in the experiment (see Figure 1).
Figure 1: The three mazes used in the experiment. a: Multiple ways maze, 
b: ZigZag maze and c: Deception maze.

The layout of the mazes is chosen to best demonstrate the following 
effects:

1. A large number of potential ways to reach the target location 
   (Multiple ways maze).
2. A large amount of open space in the maze with small entrances 
   and exits (ZigZag maze).
3. A large amount of deception in the maze, where roads lead very 
   closely to the target location but end up a dead end (Deception 
   maze).

In our test mazes the starting location is always (0,0) and the target 
location is always \((N_x, N_y)\).

2.2 Mental and physical rehearsal

The robot’s goal is to train its neural network in navigating the robot 
along the shortest path through the maze. The robot trains the neural 
network by rehearsal. There are two methods of rehearsal:

1. Physical rehearsal
2. Mental rehearsal
In physical rehearsal the robot can physically and mentally walk through the maze (changing location in both the physical and the mental maze). In mental rehearsal the robot can mentally walk through the maze (standing still in the physical maze but changing location in the mental maze). The robot’s goal is to reach the target location of the mental maze, taking the least amount of steps possible. The robot is allowed to move a maximum of 50 steps through the maze. Each step the robot moves in one of four possible directions (North, East, South and West). In order to navigate the maze efficiently, the robot needs to know the shortest path through the maze. In both modes of rehearsal the robot computes the shortest path through the maze by applying Dijkstra’s shortest path algorithm on the mental maze. The mental maze is the robot’s view on reality whether it is in a mental or a physical cycle. The shortest path the robot learns is based on its mental maze. The difference between mental and physical rehearsal is that the robot is confronted with the layout of the physical map when it is in physical rehearsal, because it physically experiences its whereabouts. When the robot’s mental maze is inconsistent with its physical experience, the mental maze is altered to correspond to the robot’s newly found knowledge. This means that the state of the explored square is added to the KSD and a new mental map is built reflecting this new data in the known section of the mental maze. This “reality check” makes it harder for the robot to train false hypotheses. In mental rehearsal, however, training false hypotheses will not be uncommon in the beginning stages of the learning process.

2.3 Neural network

The robot navigates through the maze using a single layered feedforward neural network. The neural network learns an optimal direction for every square in the maze. The input of the neural network is the location of the square that contains the robot, and the output is the direction the robot will move to (see Figure 2). If the maze is of the size $N_x \times N_y = 10$, there will be 100 ($N_x \times N_y$) possible inputs, one for each possible square in the maze. There are four possible outputs. These outputs are the directions the robot can move to (North, East, South and West). Because the size of the input layer is equal to the amount of squares in the maze, the neural network will grow linearly with the size of the maze.
Figure 2: A single layered feed forward neural network for maze navigation in a grid maze.

2.4 The weights

A weight in the neural network is of the form: $W_{xy,d}^t$, where $xy$ represents the coordinates of a location in the maze (input), $d$ is one of the four possible directions (output) and $t$ denotes the time. Each input is connected to each output and each connection has a weight. The weights can have any value between 0 and 1 and all weights have a starting value of 0.5: This means that the weights are non biased and that all the outputs in the beginning are as likely to be wrong as they are to be right. During rehearsal the weights are updated as described below.

Updating weights in physical rehearsal

When the taken direction makes the robot move along the shortest path, the weights for the given direction are strengthened by the learning rate ($\alpha$).

$$W_{xy,d}^t = W_{xy,d}^{t-1} + \alpha$$  \hspace{1cm} (1)

When the taken direction does not move the robot along the optimal path, the weights for the chosen direction are weakened.

$$W_{xy,d}^t = W_{xy,d}^{t-1} - \alpha$$  \hspace{1cm} (2)

When a robot moves into a wall, the weights of the chosen direction are weakened even more.

$$W_{xy,d}^t = W_{xy,d}^{t-1} - \text{WallCost} \cdot \alpha$$  \hspace{1cm} (3)

Updating weights in mental rehearsal

In mental rehearsal, entities learn slower than in normal rehearsal [4].
The $\alpha$ in mental rehearsal is reduced by Mental Learning Rate ($MLR$), representing this slower rate of learning. When the taken direction makes the robot move along the optimal path, the weights for the chosen direction are strengthened.

$$W_{xy,d}^t = W_{xy,d}^{t-1} + \alpha * MLR \quad (4)$$

When the taken direction does not move the robot along the optimal path, the weights for the chosen direction are weakened.

$$W_{xy,d}^t = W_{xy,d}^{t-1} - \alpha * MLR \quad (5)$$

When a robot moves into a wall in the unknown section of his mental maze, the weights of the chosen direction are weakened even more.

$$W_{xy,d}^t = W_{xy,d}^{t-1} - WallCost * \alpha * MLR \quad (6)$$

When a robot moves into a wall that is known to the robot in the KSD, the weights of the chosen direction are weakened as if the robot was practicing physical rehearsal.

$$W_{xy,d}^t = W_{xy,d}^{t-1} - WallCost * \alpha \quad (7)$$

**Updating remaining directions**

After updating $W_{xy,d}^t$, the weights of the remaining directions ($W_{xy,d'}^t$)(where $d'$ represents all directions other than $d$) will be updated with $\frac{-3}{3}$ of the value by which $W_{xy,d}^t$ is updated.

$$W_{xy,d'}^t = W_{xy,d'}^{t-1} + \frac{W_{xy,d}^{t} - W_{xy,d}^{t-1}}{3} \quad (8)$$

So if all weights are 0.5 and $W_{11,North}^1$ is updated with 0.3 from 0.5 to 0.8, $W_{11,West}^1$, $W_{11,East}^1$ and $W_{11,South}^1$ will be updated with -0.1 from 0.5 to 0.4. Because the range of the weights is between 0 and 1, all the weights with a value smaller than 0 are set to 0 and all the weights bigger than 1 are set to 1, after the weights are updated.

2.4.1 Settings

In this experiment $\alpha$ has been set to 0.1: this $\alpha$ showed the best results in a pilot test done with random mazes. $MLR$ has been set on 0.25, so the effective learning rate in mental rehearsal is 0.025. This is similar to the learning rate of mental rehearsal found by Feltz [3]. $WallCost$ has been set to 2.0 so the effective learning rate when colliding with walls is 0.2. The values of the different parameters used in the experiment are summarized in Table 1.
Table 1: Parameters of the Experiment

<table>
<thead>
<tr>
<th>parameter</th>
<th>value</th>
</tr>
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<tbody>
<tr>
<td>Amount of runs per maze</td>
<td>40</td>
</tr>
<tr>
<td>Amount of cycles per run</td>
<td>40</td>
</tr>
<tr>
<td>$Max_{steps}$</td>
<td>50</td>
</tr>
<tr>
<td>$N_x$ and $N_y$</td>
<td>10</td>
</tr>
<tr>
<td>$\alpha$</td>
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</tr>
<tr>
<td>$W_{xy,d}^0$</td>
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</tr>
<tr>
<td>MLR</td>
<td>0.25</td>
</tr>
<tr>
<td>WallCost</td>
<td>2.0</td>
</tr>
</tbody>
</table>

2.5 Optimal path

The aim of this experiment is to train the robot to walk via the shortest path through the maze. Its shortest path is calculated using Dijkstra’s optimal path algorithm. This algorithm assigns a value to every square representing the minimal amount of steps that is needed for the robot to reach that square. The algorithm starts by assigning a value of 0 to the location of the robot. For every other square, the value assigned to that square equals the lowest value of its neighboring squares +1. The algorithm runs multiple times to ensure all the squares have the correct value. Every time the robot moves into a different location the optimal path to the target location is recalculated. This ensures that when the robot moves off his original path, he will be trained to walk the optimal path from his new location. This shortest path algorithm can also tell when the target location is inaccessible: When a square is inaccessible, there is no minimum steps value for that square.

2.6 Experimental setup

There are two kinds of experimental setups.

1. A physical run, training maze navigation with 40 physical rehearsal cycles.

2. A mental and physical run, training maze navigation alternating physical with mental cycles to a total of 40 physical and 40 mental cycles.

A cycle is a sequence of steps. Each step, the robot makes one move, updates his KSD, reviews the mental maze and updates the weights of its neural network. A cycle ends when the robot has reached the target location or when the maximum amount of steps ($Max_{steps} = 50$) has been taken. After every cycle the performance measure will be calculated (described below). Furthermore, at the start of every mental rehearsal cycle the percentage of squares that is known to the robot will be calculated.
2.7 Performance measure

The performance of the robot will be measured by the minimal amount of steps needed to complete the task divided by the amount of steps it took for the robot to reach its target.

\[
PerformanceMeasure = \frac{MinSteps}{StepsTaken} \tag{9}
\]

The minimal amount of steps needed to complete the task will be calculated at the beginning of the experiment. The performance measure is a number between 0 and 1: the higher the performance measure, the better the robot is performing.

If the robot does not reach the target location another performance measure has to be used. When the robot fails to reach its target, the normalised average Manhattan distance between the robot’s location and the target location is used as the performance measure.

\[
\sum_{Step=1}^{MaxSteps} (\delta Y_i + \delta X_i) \over MaxSteps = AvgDistance \tag{10}
\]

The distance measure is normalised by dividing it by the maximum distance (MaxDistance) from any point in the maze to the target location.

\[
\frac{AvgDistance}{MaxDistance} = a \tag{11}
\]

The performance measure then becomes:

\[
PerformanceMeasure = (1 - a) * \frac{MinSteps}{MaxSteps} \tag{12}
\]

Because \(a\) is always between 0 and 1 and \(\frac{MinSteps}{StepsTaken} \geq \frac{MinSteps}{MaxSteps}\) a robot reaching its target location always has a higher performance measure than a robot not reaching its target location.

3 Results

In this section the results of the experiment are published in the following order:

1. The performance of the robot using only physical cycles compared to the performance of the robot alternating between physical and mental cycles. This section attempts to answer what the general effect of mental rehearsal is on the performance of the robot in the maze navigation task.

2. The influence of the performance level of the robot on the effect of a mental rehearsal cycle. This section attempts to answer in what way the performance level of the robot influences the effect of mental rehearsal on the performance measure.
3. The influence of the robot’s knowledge about the maze on the effect of a mental rehearsal cycle. This section attempts to answer in what way the knowledge of the robot about the maze influences the effect of mental rehearsal on the performance measure.

4. The influence of running a mental cycle on the amount of wall collisions during the next physical cycle. This section attempts to answer to what degree using mental rehearsal prevents wall collisions in physical rehearsal.

All results shown are an average of 40 experiment runs. This amounts to 40 “physical only” runs and 40 “physical and mental” runs, for every maze, per run.

3.1 Performance physical - Performance mental and physical

The graphs in figure 3 to 6 show the effect of mental rehearsal on the performance of the robot in the maze navigation task. The X-axis displays the amount of cycles the robot has taken. The Y-axis displays the performance of the robot at the end of the cycle.
Figure 3: performance in the three mazes. a: Multiple Ways maze, b: ZigZag maze, c: Deception maze. in both “mental and physical” (M&P) and “physical only” (P) cycles.
Figure 4: The performance of the three mazes averaged.
Figure 5: performance increase in the three mazes. a: Multiple Ways maze, b: Zig Zag maze, c: Deception maze. in both “mental and physical” (M&P) and “physical only” (P) cycles.
3.1.1 Explanation of charts

In all three mazes, the average performance of a robot using both mental and physical rehearsal is higher than that of a robot using only physical rehearsal. However, the robot has to reach a certain performance level in order for mental rehearsal to have an effect on performance. In the graphs of all three mazes (Figure 3 & 5) one can see that mental rehearsal has no significant effect on performance in the beginning of a run, starts to take effect after the robot reached a certain performance level and increases in effect as the run progresses. 

The enhancement of mental rehearsal in the deception maze is less than in the other two mazes (Figure 3c & 5c). This is because the performance measure in physical rehearsal is also lower in the deception maze than in the other two mazes. Because mental rehearsal needs a certain performance level to have effect, and because the performance level of the robot increases slower in more difficult mazes, it can be concluded that the timing of the effect of mental rehearsal is dependant on the difficulty of the maze. At the end of the graphs there is a decrease in the effect of mental rehearsal: This is because at the end of each run the performance converges to the maximum of 1.

Figure 4 & 6 display that the use of mental rehearsal gives an average performance increase of approximately 5%. However, the increase becomes 13% when measuring starts only after the robot has reached a performance level of at least 0.4.
3.2 Effect of mental rehearsal based on the performance level of the robot

The graphs in figure 7 & 8 show the correlation between the performance level of the robot and the effect of mental rehearsal on performance. The X axis displays the performance level of the robot in its last physical cycle. The Y axis displays the performance increase gained from a mental rehearsal cycle.
Figure 7: performance increase based on the performance level of the robot, in the three mazes. a: Multiple Ways maze, b: ZigZag maze, c: Deception maze.
3.2.1 Explanation of charts

The graph of the Deception maze (Figure 7c) shows that mental rehearsal can have a negative effect on the performance measure when it is used at a low performance level. This coincides with the previous findings that there is a minimal performance level needed in order for mental rehearsal to positively enhance performance. Figure 8 suggests that on average this minimal performance is approximately 0.4.

When mental rehearsal does start to take effect on the performance, the effect is parabolically shaped. The effect peaks at a performance level of approximately 0.7 (Figure 7 & 8. After this peak it decreases again, but never becomes negative.

3.3 Effect of mental rehearsal in relation to the percentage of squares known to the robot

The graphs in figure 9 show the effect of mental rehearsal based on the robot’s knowledge of the maze. This knowledge is represented in the percentage of maze squares that is known to the robot. The percentage is calculated by dividing the total amount of squares in the maze by the amount of squares in the KSD with a value other than unknown. The X axis displays the percentage of squares known to the robot. The Y axis displays the performance increase gained from a mental rehearsal cycle.
Figure 9: Performance increase based on the amount of knowledge the robot has about the maze, in the three mazes. a: Multiple Ways maze, b: ZigZag maze, c: Deception maze.
3.3.1 Explanation of charts

The results in figure 9 show no correlation between the knowledge of the robot about the maze and the effect of mental rehearsal on the performance. It can now be concluded that the increasing effect of mental rehearsal is due to the increase in the robot’s performance level and not due to the increase of the robot’s knowledge about the maze.

3.4 Wall collisions physical - Wall collisions mental and physical

The graphs in figure 10 to 12 show the effect of a mental rehearsal cycle on the amount of wall collisions in the next physical rehearsal cycle. Collision prevention is measured by comparing the amount of walls hit when learning the mazes using only physical rehearsal to the amount of walls hit when learning the mazes using both physical and mental rehearsal. Only wall collisions in physical rehearsal are counted. The X axis displays the cycle the robot was in. The Y axis displays the amount of walls the robot hit in that cycle.
Figure 10: Wall collisions in the three mazes: a. Multiple Ways, b. ZigZag, c. Deception. in both "mental and physical" (M&P) and "physical only" (P) cycles.
Figure 11: Total difference in wall collisions between P and M&P in the three mazes: a. Multiple Ways, b. ZigZag, c. Deception.
Figure 12: Total difference in wall collisions between P and M&P averaged over the three mazes.

3.4.1 Explanation of charts

On average mental rehearsal prevents 1.41 wall collisions in one cycle. Contrasting with the delayed effect of mental rehearsal on performance, the effect of mental rehearsal on wall collisions is immediately present at the start of each run.

4 Conclusions

Given the results of the experiments, conclusions can be drawn about these subjects:

1. The performance of the robot in the maze navigation task.
   1.1 The influence of the performance level of the robot on the effect of the mental rehearsal.
   1.2 The correlation between the effect of mental rehearsal and the complexity of the task.
   1.3 The correlation between the effect of mental rehearsal and the knowledge of the robot about the task.
   1.4 The increase in the energy efficiency of the learning process by using mental rehearsal.

2. The damage reduction achieved by using mental rehearsal.

4.1 Effect of mental rehearsal on the performance measure of the maze navigation task

A robot that starts using mental rehearsal at a performance level of at least 0.4 will have a performance increase of approximately 13% compared to a robot not using mental rehearsal. This is comparable to the effect found in the research of Felthz and Landers[3]. The effect
of mental rehearsal is parabolically shaped and has its peak when the 
robot reaches a performance level of approximately 0.7. However; it 
has been observed that this performance increase is correlated with 
two factors.

1.1 The Performance level of the robot in the maze navigation task.
1.2 The layout of the maze; which influences the complexity of the 
maze navigation task.

4.1.1 Correlation between the performance level of the 
robot and the effect of mental rehearsal

When viewing the effect of mental rehearsal in correlation with the 
performance level of the robot (see Figure 3 to 6), it was found that 
mental rehearsal does not have a significant effect on the performance 
measure of the robot when the performance level of that robot is too 
low. In the maze navigation task used in this experiment, the perfor-
mance level needed in order for mental rehearsal to have an effect was 
dependant on the maze.

Looking at the effect of mental rehearsal on the performance mea-
sure, one can see that the effect increases as the performance level of 
the robot increases. In figure 5 & 6, it is clear that the effect of mental 
rehearsal decreases after a certain time. This decrease is due to reach-
ing the maximum in the performance measure. When the robot using 
mental rehearsal has reached the maximum performance measure of 
1.0, the robot not using mental rehearsal is probably still learning; the 
difference in performance measure between the two robots decreases 
after this point has been reached because the performance measure of 
the robot using mental rehearsal cannot increase any further.

The need of a certain performance level in order for mental rehearsal 
to work, as well as the lack of correlation between the knowledge of 
the robot about the maze and the effect of mental rehearsal suggest 
that mental rehearsal is not a self sufficient learning method: Rather 
than training a neural network from the ground up, it strengthens 
the already learned patterns. Because the robot’s knowledge about 
the maze has no direct relation with the weights of the neural network, 
mental rehearsal is not directly correlated with knowledge of the maze.

4.1.2 Correlation between the layout of the maze and 
the effect of mental rehearsal

It is clear from figure 3 to 6 that the effect of mental rehearsal is not 
identical for the three different mazes. This can be explained by looking 
at the percentage of walls in the maze. The mental rehearsal function 
used is more effective in a wall rich environment. This increase in effect 
is due to the learning function: Because known walls are a certainty 
in the mental maze, the neural network weights that lead to a known 
wall are updated in mental rehearsal with the $\alpha$ of physical rehearsal 
instead of the lower $\alpha$ of mental rehearsal.
The relatively low effect of mental rehearsal in the deception maze is explained by looking at the nature of the mental maze. When a maze is deceptive it means that partial information about the maze is more likely to lead to a false conclusion about the further layout of the maze. Because a mental maze is constructed based on partial information about the physical maze it can be concluded that the mental maze in tends to less similar to the physical maze the more deceptive the physical maze is.

4.1.3 Correlation between the knowledge the robot has about the maze and the effect of mental rehearsal

In contrast with expectations, no correlation was found between the effect of mental rehearsal, and the knowledge the robot has about the layout of the maze. (see Figure 9)

4.1.4 Energy cost reduction achieved by using mental rehearsal

Given the found increase in performance by the use of mental rehearsal, it could be concluded that using mental rehearsal is potentially more energy efficient than using only physical rehearsal. However, the average percentage of energy cost increase of a mental rehearsal run compared to a physical run must be lower than the average percentage of performance increase received from using mental rehearsal. The average performance increase gained from mental rehearsal can be boosted by fine-tuning the timing of using mental rehearsal. The effect of mental rehearsal is positive when the robot has an existing performance of at least 0.4. (This is the threshold for this maze navigation task but could be different when mental rehearsal is applied for other tasks.) Applying mental rehearsal regardless of the threshold is less energy efficient than applying it after the threshold. Taking into account the threshold therefore increases the average performance and increases the energy cost reduction.

Next to the timing of applying mental rehearsal, the energy cost reduction is also dependant on the energy cost of the physical rehearsal and the energy cost of the mental rehearsal for the task that mental rehearsal is applied to. The energy cost of the mental rehearsal will be strongly dependant on the efficiency of the code of the mental simulation. The physical energy cost will be strongly dependant on the physical strain and complexity of the task. It is safe to assume that the more physically fatiguing a task is, the more energy reduction you will get from applying mental rehearsal.

4.2 Damage reduction by mental rehearsal

Using mental rehearsal in the maze navigation task has led to a decrease in wall collisions during physical rehearsal. These wall collisions represent potential damage to the robot. In a maze navigation task
like the one in this experiment, avoiding wall collisions has two benefits. It prevents damage and it decreases the amount of steps where nothing is explored. Avoiding walls in physical cycles enhances the robot’s mental maze because more exploration ensures more similarity between the mental maze and the physical maze.

More research is needed to conclude applying mental rehearsal for a longer period than the period of 40 cycles in this experiment will prevent more wall collisions.

5 Future research

5.1 Find a better performance measure

The performance measure used in this experiment is not ideal. When the robot has not yet reached its target location and the performance has to be measured, that performance is based on the average distance between the robot and the target location. There are mazes like the Deception maze where this performance measure does not point out the best performing robot. In a maze that has many different ways leading to a square very close to the target location, but never reaching the target location, and one way going all around the edges of the maze but eventually reaching the target location, the average distance of the robot taking the wrong way is smaller than the average distance of the robot taking the right way. However, an advantage of this performance measure is that the robot can calculate its own performance measure. This is useful when applying techniques where the robot can autonomously determine to use mental rehearsal, based on his own performance level. This makes the robot more self sufficient. However, these kinds of techniques are not used in this experiment and therefore the performance measure is not ideal.

5.2 Apply mental rehearsal to a physical robot instead of a simulated robot

Because the results of this experiment are generated in a simulation, there is no reality gap problem. This means that the results found in this research will not be the same results found when applying mental rehearsal in a physical robot. The benefits of mental rehearsal: Energy cost reduction and damage reduction, are only present in the physical world therefore results for mental rehearsal in a physical robot have to be obtained to know the true usefulness of mental rehearsal for robots.


References


