

# JoVE: Science Education

## Mental Rotation

--Manuscript Draft--

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**PI:** Jonathan Flombaum  
**Psychology Education Title:** Mental Rotation

**Overview:**

Visual mental imagery refers to the ability to conjure images in one’s mind’s eye. It is an ability that seems to support important human behaviors in many contexts. For example, people report visualizing routes and maps when planning a route or giving directions. They report visualizing movements, such as swinging a bat, to prepare for an actual action. They also report visualizing rotating objects in order to consider how an object might fit into a receptacle or clear a barrier.

This video demonstrates how to use the mental rotation procedure in order to investigate visual mental imagery.

**Procedure:**

1. Stimulus design.
  - 1.1. Present the stimuli for this experiment – letters and numbers, along with their mirror images (**Figure 1**) – in various rotations.
  - 1.2. Use PowerPoint, Keynote, or a similar program to generate the stimuli.
  - 1.3. For this experiment, use the uppercase letter “R” and the lowercase letter “g,” along with the numbers “4” and “7.”
  - 1.4. In PowerPoint, make one copy of each of the four characters. Use the Helvetica Light font for this experiment.
  - 1.5. Make a second copy of each character and flip them to produce a mirror image of each.
  - 1.6. Make 12 copies of each of the 4 characters and their mirror images.
  - 1.7. Rotate each of the 12 copies by an increasing increment of 15°. The original copy of each is 0°, the next is 15°, then 30°, and so on, until 180°. Reference **Figure 2** to see the full set of stimuli used for this experiment.
  - 1.8. From the 13 rotated copies of each stimulus and its mirror image, generate the stimuli for each individual trial. A trial consists of one of the 4 non-mirror images printed at the top of a page. The bottom of the page includes that letter or number and its mirror image at one of the 12 rotations (**Figures 3 and 4**).
  - 1.9. Make a page for each trial of the experiment. Each of the 4 numbers/letters have 13 trial pages, so make sure there are 52 pages total and print them out.

- 1.10. Number the backs of the pages 1-52. The number on each page is “the number tag.” The number a page is labelled with does not matter. However, when numbering the pages, also make a key, a table that reports the nature of the trial on each page and the correct answer (left or right), so responses can be associated with individual trials later. Create the key to look something like an Excel spreadsheet labelled “Mirror Drawing Key” (**Table 1**).
- 1.11. In order to associate results with the content of each trial, a place to record the results is needed, so make another spreadsheet with a column for the trial number, a column for the number tag of that trial, a column for the response given (right or left), and a column for the time it takes the participant to produce a response (**Table 2**). Print out this response sheet.
- 1.12. In addition, make a “demo” page to use in order to explain the instructions. Have it show an example of one of the characters, its mirror image, and some examples of the character at one of the rotations. Label it clearly (**Figure 5**).
- 1.13. In addition to printed versions of the trial and demo pages, acquire a stopwatch for the experiment, and it is also useful to have an assistant to help with timing and recording responses.

## 2. Procedure.

- 2.1. Use the demo page to explain the instructions to the participant: “This experiment will investigate your ability to rotate objects using visual imagery. On each trial, you will be asked to decide which one of two images is a rotated version of a familiar number or letter. The alternative will be a mirror image rotation of the same number or letter. Here is one example: the number 3. And here is its mirror image. In a trial, you will see the original 3, along with something like the two examples on the bottom of the page, the rotated 3 and a rotation of its mirror image. You will say “left” or “right” to indicate which one you think is the original. You should respond as quickly as possible without sacrificing accuracy. In other words, respond as soon as you are sure of the answer, but not sooner.”
- 2.2. Shuffle the 52 test pages to randomize the order. After shuffling, enter the number tags of the trials in the order they will be presented in on the response sheet.
- 2.3. Start the experiment. Place the stack of pages face-down between the experimenter and the participant, the number tags facing up.
- 2.4. Have the assistant hold the stopwatch.
- 2.5. On each trial, have the assistant say, “Go,” when they start the timer. At this signal, flip over the page for that trial. Have the participant study the page and say “right” or “left” to indicate which character is the answer for that trial.

- 2.6. When the participant reports a response, have the assistant stop the timer. Then, record the response time and the answer given on the response sheet.
- 2.7. Repeat this procedure for all 52 trials.
3. Analysis.
  - 3.1. When the experiment is done, analyze the data.
  - 3.2. Enter the handwritten number tags, responses, and response times into a digital copy of the response sheet, and save it with a new name, for example, "Participant 1 MR responses" (**Table 3**).
  - 3.3. Sort the data by the number tags, 1-52.
  - 3.4. Open the response key and sort by number tag. Cut and paste the contents of the response key into the sheet with the participant responses, so now there are columns reporting both the responses and response times of the participant, and the details of each trial.
  - 3.5. Add one more column to the end of the sheet, labelled "Response Correct?" Compare the response given with the correct response in each row, and enter a 1 in the response correct row if the answer given was correct or a 0 if it was not.
  - 3.6. Summarize the results. Average the "Response Correct?" column to see the overall proportion of trials with correct responses. This should be very high or perfect for most participants. Average the response time column to get a sense of the overall response times. That column can also be averaged while filtering by the letter on the trial and/or the orientation of the letter.

### Representative Results:

A common way to graph the results is to plot the response time for each character as a function of the rotation of the character (and its mirror image) (**Figure 6**).

One of the most interesting common results associated with mental rotation tasks is that the amount of time it takes to produce a response is proportional to the degree of rotation distinguishing the target character and its rotated pair. In other words, the time it takes to rotate an object mentally seems proportional to the time it would take to actually rotate physical objects in order to place them at the same orientation. This suggests that mental rotation relies on mechanisms that really try to simulate physical space in the brain, even though no pieces of the brain rotate.

### Applications:

One of the main practical applications for mental rotation tasks is to identify people who are especially good at visual thinking about physical spaces. Think about the skills it takes to be a good architect, mechanical engineer, an expert carpenter, or welder. Some people are really good

**Comment [JR1]:** Potential images:

Architects: [http://www.shutterstock.com/pic-165672179/stock-photo-close-up-of-two-architects-discussing-plan-together-at-desk-with-blueprints.html?src=3B\\_MkT3OuNavHPk2JEpujA-1-0](http://www.shutterstock.com/pic-165672179/stock-photo-close-up-of-two-architects-discussing-plan-together-at-desk-with-blueprints.html?src=3B_MkT3OuNavHPk2JEpujA-1-0)

Welder: <http://www.shutterstock.com/pic-185697230/stock-photo-welder-working-with-electrode-at-semi-automatic-arc-welding-in-manufacture-production-plant.html?src=SGk74XSvpj00YnY7B0ktbA-1-1>

Mechanical Engineer: <http://www.shutterstock.com/pic-74079550/stock-photo-technical-drawing-and-tools-in-hand.html?src=VXKRJIiikM-faCr-CTYtAA-1-33>

Carpenter: <http://www.shutterstock.com/pic-231222958/stock-photo-close-up-carpenter-s-hands-that-work-with-cutter.html?src=PGsM6nBDhjEUE9K-jRuUA-1-5>

Not mentioned as an example, but sculpting seems applicable: <http://www.shutterstock.com/pic-179230544/stock-photo-sculptor-working-on-head-sculpture.html?src=TVqYpelqRsc4q8oB33WrVg-1-0>

at using mental imagery to guide their actions, and some people are not very good at all, reporting that they don't even really see pictures in their mind's eye the way most people do. The mental rotation test is a good way to identify exceptionally good and exceptionally bad visualizers in order to help people find the best uses of their abilities.

**Legend:**

Figure 1: Sample stimuli for a mental rotation task. The top rows show two characters (R and 4) and a copy of each rotated. The bottom row shows a mirror image of each (on the right side of each pair) and a rotated version of each, as well. The mental rotation task involves identifying rotated versions of familiar characters and distinguishing them from rotated versions of their mirror images.

Figure 2: A complete set of stimuli for the mental rotation task. Four characters (3, R, 4, and g), each paired with their mirror images and rotated in 15° increments between 0 and 180.

Figure 3: A sample test page for one trial of the mental rotation experiment. The participant must report whether the character on the left or the right (below the line) is the rotated "R" (as opposed to its mirror image rotation).

Figure 4: A sample test page for one trial of the mental rotation experiment. The participant must report whether the character on the left or the right (below the line) is the rotated "4" (as opposed to its mirror image rotation).

Figure 5: An instruction sheet that presents one of the characters, its mirror image, and a rotation of each in order to facilitate explanation of the procedure to the participant.

Figure 6: Results from the mental rotation task. Response times are plotted for each of the characters as a function of the amount of rotation in a given trial. Generally, response times are longer the more a character is rotated from its canonical orientation, suggesting that brain mechanisms simulate physical transformations.

Table 1: An example of a key that reports the nature of the trial on each page and the correct answer (left or right).

Table 2: An example of a results spreadsheet to record the trial number, the number tag of that trial, the response given (right or left), and the time it takes the participant to produce a response.

Table 3: An example of a completed response sheet.

Number Tag	Character
1	3
2	g
3	g
4	g
5	g
6	4
7	3
8	3
9	4
10	R
11	g
12	g
13	g
14	3
15	4
16	R
17	R
18	R
19	g
20	R
21	3
22	4
23	R

24	4
25	3
26	4
27	R
28	4
29	4
30	3
31	R
32	3
33	4
34	3
35	3
36	R
37	4
38	4
39	R
40	R
41	8
42	3
43	3
44	4
45	4
46	3
47	R

48

g

49

g

50

g

51

R

52

g



Angle	Correct Answer
60	RIGHT
75	RIGHT
30	RIGHT
60	LEFT
165	RIGHT
105	LEFT
15	LEFT
165	LEFT
180	LEFT
15	RIGHT
180	RIGHT
45	RIGHT
105	RIGHT
45	RIGHT
15	LEFT
60	LEFT
45	LEFT
150	LEFT
0	RIGHT
30	LEFT
120	LEFT
90	LEFT
75	LEFT

135	RIGHT
180	LEFT
45	LEFT
90	RIGHT
0	LEFT
120	LEFT
135	RIGHT
135	LEFT
30	LEFT
75	LEFT
105	LEFT
150	LEFT
105	RIGHT
60	RIGHT
30	LEFT
120	RIGHT
180	RIGHT
135	RIGHT
0	LEFT
90	LEFT
150	RIGHT
165	LEFT
75	RIGHT
165	LEFT

90	RIGHT
150	RIGHT
15	LEFT
0	RIGHT
120	RIGHT

<b>Trial #</b>	<b>Number Tag</b>	<b>Response Given</b>
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
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52

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## Response Time

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Trial #	Number Tag
4	1
38	2
40	3
26	4
10	5
49	6
16	7
45	8
35	9
17	10
12	11
5	12
21	13
25	14
33	15
42	16
31	17
9	18



46	19
3	20
18	21
28	22
24	23
6	24
47	25
7	26
50	27
27	28
48	29
13	30
36	31
11	32
29	33
51	34
1	35
8	36
52	37

2	38
32	39
43	40
37	41
19	42
14	43
22	44
41	45
23	46
34	47
20	48
44	49
39	50
15	51
30	52

<b>Response Given</b>	<b>Response Time</b>
RIGHT	4876
RIGHT	6758
RIGHT	3579
LEFT	8752
RIGHT	6494
LEFT	6587
LEFT	3434
LEFT	9172
LEFT	1856
RIGHT	6818
RIGHT	4797
RIGHT	5378
RIGHT	3301
RIGHT	1393
LEFT	3937
LEFT	5827
LEFT	6004
LEFT	6174

RIGHT	6619
LEFT	2276
LEFT	4176
LEFT	7819
LEFT	7368
RIGHT	4984
LEFT	4495
LEFT	5476
RIGHT	7919
LEFT	7182
LEFT	5793
RIGHT	8986
LEFT	9457
LEFT	7903
LEFT	9703
LEFT	9565
LEFT	9341
RIGHT	2849
RIGHT	2355

LEFT	2094
RIGHT	7338
RIGHT	5431
RIGHT	2734
LEFT	5978
LEFT	3305
RIGHT	5273
LEFT	4472
RIGHT	2353
LEFT	8211
RIGHT	2049
RIGHT	9719
LEFT	9562
RIGHT	1282
RIGHT	3548

Number Tag2	Character	Angle
1	3	60
2	g	75
3	g	30
4	g	60
5	g	165
6	4	105
7	3	15
8	3	165
9	4	180
10	R	15
11	g	180
12	g	45
13	g	105
14	3	45
15	4	15
16	R	60
17	R	45
18	R	150

19	g	0
20	R	30
21	3	120
22	4	90
23	R	75
24	4	135
25	3	180
26	4	45
27	R	90
28	4	0
29	4	120
30	3	135
31	R	135
32	3	30
33	4	75
34	3	105
35	3	150
36	R	105
37	4	60

38	4	30
39	R	120
40	R	180
41	g	135
42	3	0
43	3	90
44	4	150
45	4	165
46	3	75
47	R	165
48	g	90
49	g	150
50	g	15
51	R	0
52	g	120

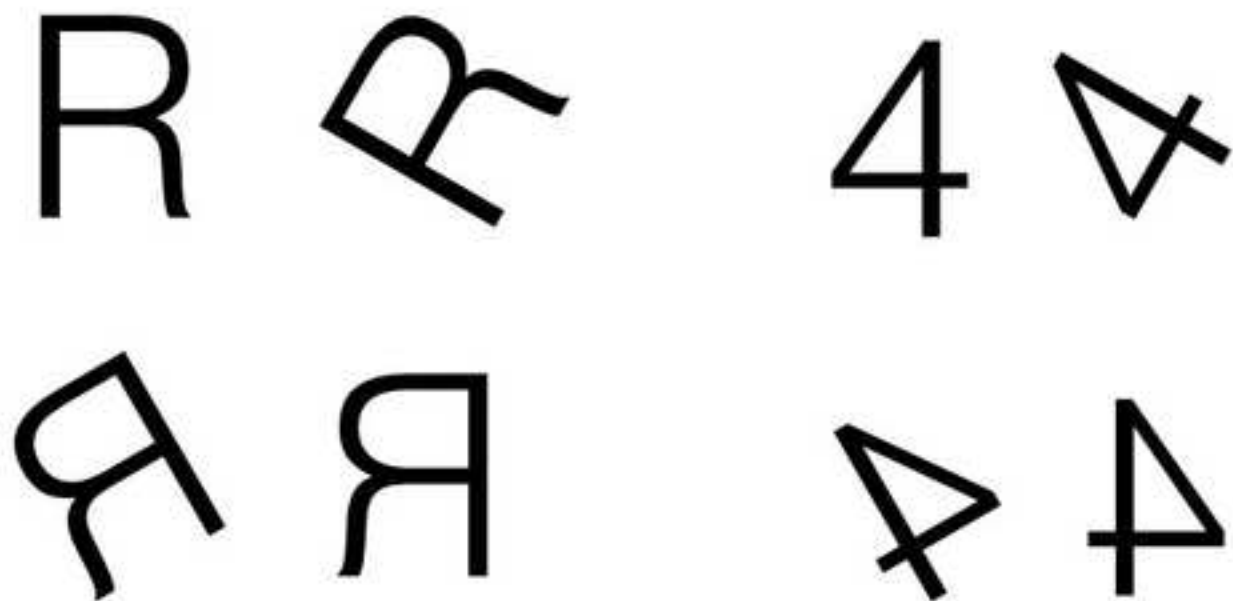


Correct Answer	Answer Correct?
RIGHT	1
RIGHT	1
RIGHT	1
LEFT	1
RIGHT	1
LEFT	1
LEFT	1
LEFT	1
LEFT	1
RIGHT	1
RIGHT	1
RIGHT	1
RIGHT	1
RIGHT	1
LEFT	1
LEFT	1
LEFT	1
LEFT	1

RIGHT	1
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RIGHT	1
LEFT	1
LEFT	1
RIGHT	1
LEFT	1
RIGHT	1
LEFT	1
RIGHT	1
RIGHT	1
LEFT	1
RIGHT	1
RIGHT	1

**Sample Stimuli for Mental Rotation Task**



## Stimuli for Mental Rotation Task

[illegible]

Sample Test Page

Which of the two  
characters below is the: R

---



Sample Test Page

Which of the two  
characters below is the: 4



Instructions Sheet

Original

3

Mirror Image

ε

Ɔ

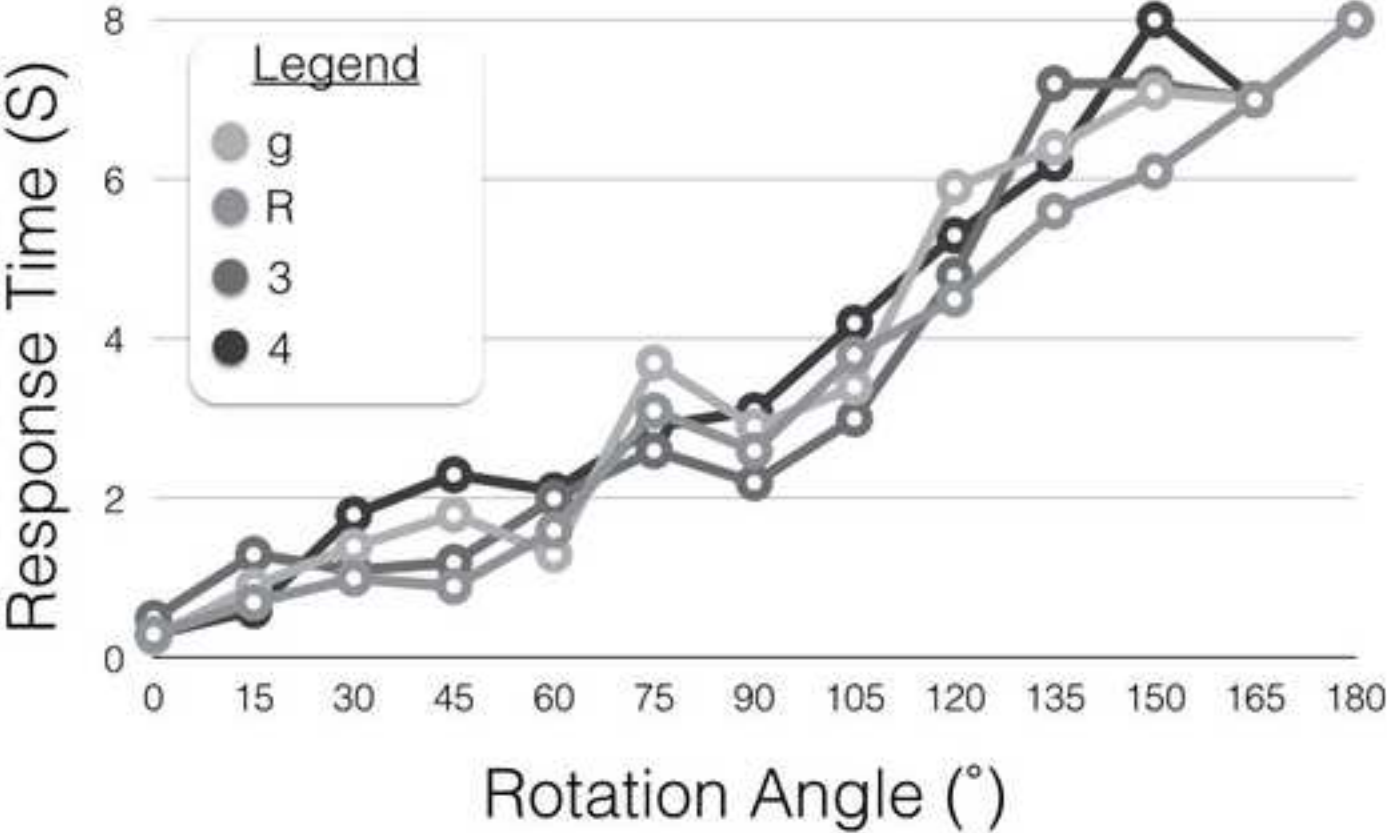
Rotated Original  
(105°)

ω

Rotated Mirror Image  
(105°)



# Response Times as a Function of Rotation



**PI:** Jonathan Flombaum  
**Psychology Education Title:** Mental Rotation

**Overview:**

Visual mental imagery refers to the ability to conjure images in one’s mind’s eye. This allows people to process visual material above and beyond the constraints of a current point-of-view; for example, a person could imagine, using their mind’s eye, how something might look in a different color, or what it’d look like made if it were made from a different material, or rotated and seen from a different perspective. It is an Mental imagery ability that seems to support important human behaviors in many contexts. For example, people report visualizing routes and maps when planning a route or giving directions. They report visualizing movements, such as swinging a bat, to prepare for an actual action. They also report visualizing rotating the rotation of the mental rotation of objects in order to consider how an object might fit into a receptacle or clear a barrier.

This video demonstrates how to use the mental rotation procedure in order to investigate visual mental imagery.

**Procedure:**

1. Stimulus design.
  - 1.1. Present the stimuli for this experiment – letters and numbers, along with their mirror images (**Figure 1**) – in various rotations.
  - 1.2. Use PowerPoint, Keynote, or a similar program to generate the stimuli.
  - 1.3. For this experiment, use the uppercase letter “R” and the lowercase letter “g,” along with the numbers “4” and “7.”
  - 1.4. In PowerPoint, make one copy of each of the four characters. Use the Helvetica Light font for this experiment.
  - 1.5. Make a second copy of each character and flip them to produce a mirror image of each.
  - 1.6. Make 12 copies of each of the 4 characters and their mirror images.
  - 1.7. Rotate each of the 12 copies by an increasing increment of 15°. The original copy of each is 0°, the next is 15°, then 30°, and so on, until 180°. Reference **Figure 2** to see the full set of stimuli used for this experiment.
  - 1.8. From the 13 rotated copies of each stimulus and its mirror image, generate the stimuli for each individual trial. A trial consists of one of the 4 non-mirror images printed at the top of a page. The bottom of the page includes that letter or number

**Commented [JS1]:** This section is brief. Can you include the term mental rotation so that it clear and not implied?

**Commented [JS2]:** Can you reword this or clarify by adding an additional sentence about processing?

and its mirror image at one of the 12 rotations (**Figures 3 and 4**).

- 1.9. Make a page for each trial of the experiment. Each of the 4 numbers/letters have 13 trial pages, so make sure there are 52 pages total and print them out.
- 1.10. Number the backs of the pages 1-52. The number on each page is “the number tag.” The number a page is labelled with does not matter. However, when numbering the pages, also make a key, a table that reports the nature of the trial on each page and the correct answer (left or right), so responses can be associated with individual trials later. Create the key to look something like an Excel spreadsheet labelled “Mirror Drawing Key” (**Table 1**).
- 1.11. In order to associate results with the content of each trial, a place to record the results is needed, so make another spreadsheet with a column for the trial number, a column for the number tag of that trial, a column for the response given (right or left), and a column for the time it takes the participant to produce a response (**Table 2**). Print out this response sheet.
- 1.12. In addition, make a “demo” page to use in order to explain the instructions. Have it show an example of one of the characters, its mirror image, and some examples of the character at one of the rotations. Label it clearly (**Figure 5**).
- 1.13. In addition to printed versions of the trial and demo pages, acquire a stopwatch for the experiment, and it is also useful to have an assistant to help with timing and recording responses.

## 2. Procedure.

- 2.1. Use the demo page to explain the instructions to the participant: “This experiment will investigate your ability to rotate objects using visual imagery. On each trial, you will be asked to decide which one of two images is a rotated version of a familiar number or letter. The alternative will be a mirror image rotation of the same number or letter. Here is one example: the number 3. And here is its mirror image. In a trial, you will see the original 3, along with something like the two examples on the bottom of the page, the rotated 3 and a rotation of its mirror image. You will say “left” or “right” to indicate which one you think is the original. You should respond as quickly as possible without sacrificing accuracy. In other words, respond as soon as you are sure of the answer, but not sooner.”
- 2.2. Shuffle the 52 test pages to randomize the order. After shuffling, enter the number tags of the trials in the order they will be presented in on the response sheet.
- 2.3. Start the experiment. Place the stack of pages face-down between the experimenter and the participant, the number tags facing up.
- 2.4. Have the assistant hold the stopwatch.

- 2.5. On each trial, have the assistant say, “Go,” when they start the timer. At this signal, flip over the page for that trial. Have the participant study the page and say “right” or “left” to indicate which character is the answer for that trial.
- 2.6. When the participant reports a response, have the assistant stop the timer. Then, record the response time and the answer given on the response sheet.
- 2.7. Repeat this procedure for all 52 trials.
3. Analysis.
  - 3.1. When the experiment is done, analyze the data.
  - 3.2. Enter the handwritten number tags, responses, and response times into a digital copy of the response sheet, and save it with a new name, for example, “Participant 1 MR responses” (**Table 3**).
  - 3.3. Sort the data by the number tags, 1-52.
  - 3.4. Open the response key and sort by number tag. Cut and paste the contents of the response key into the sheet with the participant responses, so now there are columns reporting both the responses and response times of the participant, and the details of each trial.
  - 3.5. Add one more column to the end of the sheet, labelled “Response Correct?” Compare the response given with the correct response in each row, and enter a 1 in the response correct row if the answer given was correct or a 0 if it was not.
  - 3.6. Summarize the results. Average the “Response Correct?” column to see the overall proportion of trials with correct responses. This should be very high or perfect for most participants. Average the response time column to get a sense of the overall response times. That column can also be averaged while filtering by the letter on the trial and/or the orientation of the letter.

### **Representative Results:**

A common way to graph the results is to plot the response time for each character as a function of the rotation of the character (and its mirror image) (**Figure 6**).

One of the most interesting common results associated with mental rotation tasks is that the amount of time it takes to produce a response is proportional to the degree of rotation distinguishing the target character and its rotated pair. In other words, the time it takes to rotate an object mentally seems proportional to the time it would take to actually rotate physical objects in order to place them at the same orientation. This suggests that mental rotation relies on mechanisms that really try to simulate physical space in the brain, even though no pieces of the brain rotate.

**Applications:**

One of the main practical applications for mental rotation tasks is to identify people who are especially good at visual thinking about physical spaces. Think about the skills it takes to be a good architect, mechanical engineer, an expert carpenter, or welder. Some people are really good at using mental imagery to guide their actions, and some people are not very good at all, reporting that they don't even really see pictures in their mind's eye the way most people do. The mental rotation test is a good way to identify exceptionally good and exceptionally bad visualizers in order to help people find the best uses of their abilities.

Mental rotation has also been an important part of neuroscience research aimed at understanding the parts of the occipital and parietal lobes involved in human vision. One of the most surprising findings is that when people mentally rotate objects without looking at them, there is an enormous amount of brain activity in visual cortex, and brain areas generally thought to be involved in seeing. In other words, the brain systems used to actually see visual stimuli are also used to imagine visual stimuli.

**Legend:**

Figure 1: Sample stimuli for a mental rotation task. The top rows show two characters (R and 4) and a copy of each rotated. The bottom row shows a mirror image of each (on the right side of each pair) and a rotated version of each, as well. The mental rotation task involves identifying rotated versions of familiar characters and distinguishing them from rotated versions of their mirror images.

Figure 2: A complete set of stimuli for the mental rotation task. Four characters (3, R, 4, and g), each paired with their mirror images and rotated in 15° increments between 0 and 180.

Figure 3: A sample test page for one trial of the mental rotation experiment. The participant must report whether the character on the left or the right (below the line) is the rotated "R" (as opposed to its mirror image rotation).

Figure 4: A sample test page for one trial of the mental rotation experiment. The participant must report whether the character on the left or the right (below the line) is the rotated "4" (as opposed to its mirror image rotation).

Figure 5: An instruction sheet that presents one of the characters, its mirror image, and a rotation of each in order to facilitate explanation of the procedure to the participant.

Figure 6: Results from the mental rotation task. Response times are plotted for each of the characters as a function of the amount of rotation in a given trial. Generally, response times are longer the more a character is rotated from its canonical orientation, suggesting that brain mechanisms simulate physical transformations.

Table 1: An example of a key that reports the nature of the trial on each page and the correct answer (left or right).

**Commented [JR3]:** Potential images:

Architects: [http://www.shutterstock.com/pic-165672179/stock-photo-close-up-of-two-architects-discussing-plan-together-at-desk-with-blueprints.html?src=3B\\_MkT3OuNayHPk2JEpujA-1-0](http://www.shutterstock.com/pic-165672179/stock-photo-close-up-of-two-architects-discussing-plan-together-at-desk-with-blueprints.html?src=3B_MkT3OuNayHPk2JEpujA-1-0)

Welder: <http://www.shutterstock.com/pic-185697230/stock-photo-welder-working-with-electrode-at-semi-automatic-arc-welding-in-manufacture-production-plant.html?src=SGk74XSvpj00YnYZB0ktbA-1-1>

Mechanical Engineer: <http://www.shutterstock.com/pic-74079550/stock-photo-technical-drawing-and-tools-in-hand.html?src=VXKRJEikM-faCr-CTYtAA-1-33>

Carpenter: <http://www.shutterstock.com/pic-231222958/stock-photo-close-up-carpenter-s-hands-that-work-with-cutter.html?src=PGsM6nBDbjFUE9K--jRuUA-1-5>

Not mentioned as an example, but sculpting seems applicable: <http://www.shutterstock.com/pic-179230544/stock-photo-sculptor-working-on-head-sculpture.html?src=TVqYpelqRsc4q8oB33WrVg-1-0>

**Commented [JS4]:** Can you provide another application? Can impairments in performance correlate with cortical activation and lesion diagnosis?

**Commented [JS5]:** Dancing also comes to mind.

Table 2: An example of a results spreadsheet to record the trial number, the number tag of that trial, the response given (right or left), and the time it takes the participant to produce a response.

Table 3: An example of a completed response sheet.