PSY 3330: Elementary Statistics for the Behavioral Sciences

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Week 9 – Introduction to the t test

Standard Deviation

To review:

1. compute deviation scores
2. compute the SS
   - $SS =$ sum of squared deviations $= \sum(X - \mu)^2$
3. determine the variance
   - average of squared deviations
   - divide SS by N
4. determine the standard deviation
   - square root of variance

Standard Deviation of Samples

If you used software (e.g., SPSS, R, Excel) to compute the standard deviation, you'd get a different answer! Here's why:

Computing SD for samples is a bit different. The basic procedure is the same:

1. compute deviation scores
2. compute the SS
3. determine the variance
   - this step is different!
4. determine the standard deviation

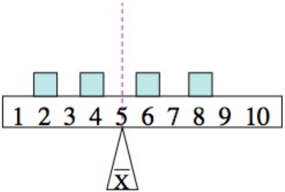
Standard Deviation (sample)

- Step 1: Compute the deviation scores
  - subtract the sample mean from every individual in our distribution.

Our sample

2, 4, 6, 8

$$\overline{X} = \frac{\sum X}{n} = \frac{2+4+6+8}{4} = \frac{20}{4} = 5.0$$



$X - \overline{X}$ = deviation scores

$2 - 5 = -3 \qquad 6 - 5 = +1$

$4 - 5 = -1 \qquad 8 - 5 = +3$

Standard Deviation (sample)

- Step 2: Determine the **sum of the squared deviations (SS).**

$X - \bar{X}$ = deviation scores

$2 - 5 = -3 \qquad 6 - 5 = +1$

$4 - 5 = -1 \qquad 8 - 5 = +3$

$$SS = \Sigma(X - \bar{X})^2$$
$$= (-3)^2 + (-1)^2 + (+1)^2 + (+3)^2$$
$$= 9 + 1 + 1 + 9 = 20$$

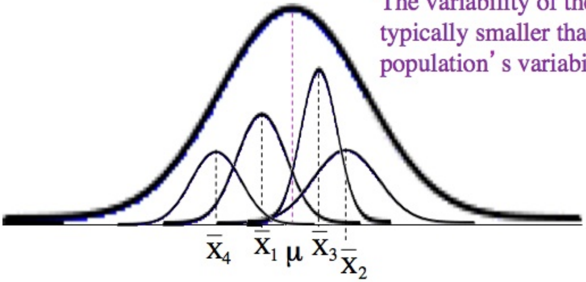
Apart from notational differences the procedure is the same as before

Standard Deviation (sample)

- Step 3: Determine the ***variance***

Recall:

Population variance = σ^2 = SS/N



The variability of the samples is typically smaller than the population's variability

Standard Deviation (sample)

- Step 3: Determine the ***variance***

  Recall:

  Population variance = σ^2 = SS/N

  The variability of the samples is typically smaller than the population's variability

  To correct for this we divide by (n-1) instead of just n

  $$\text{Sample variance} = s^2 = \frac{SS}{(n-1)}$$

Standard Deviation (sample)

- Step 4: Compute the standard deviation. Take the square root of the sample variance.

$$
\begin{aligned}
\text{standard deviation } &= s = \sqrt{s^2} \\
&= \sqrt{\frac{SS}{n-1}} \\
&= \sqrt{\frac{20}{3}} \\
&= \sqrt{6.67} \\
&= 2.58
\end{aligned}
$$

Back to hypothesis testing...

Statistical analysis follows design...

The one-sample z-test can be used when:

- 1 sample
- one score per subject
- Population mean μ and standard deviation σ are known

$$z = \frac{\overline{X} - \mu_{\overline{X}}}{\sigma_{\overline{X}}}$$

Statistical analysis follows design...

The one-sample t-test can be used when:

- 1 sample
- one score per subject
- Population mean μ is known
- Population standard deviation is not known
- Basic difference: s is used as an estimator of σ

$$t = \frac{\overline{X} - \mu_{\overline{X}}}{s_{\overline{X}}}$$

Testing hypotheses

Steps of hypothesis testing:

1. State your hypotheses
2. Set your decision criteria
3. Collect your data
4. Compute your test statistics
   - Compute your estimated standard error
   - Compute your t-statistic
   - Compute your degrees of freedom
5. Make a decision about your null hypothesis

Testing hypotheses

- What are we doing when we test the hypotheses?
  - Computing a test statistic: **Generic test**

Could be difference between a sample and a population, or between different samples

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

Based on standard error or an estimate of the standard error

Testing hypotheses

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

identical

	One sample z	One sample t
Test statistic	$z_{\bar{X}} = \dfrac{\bar{X} - \mu_{\bar{X}}}{\sigma_{\bar{X}}}$	$t = \dfrac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}}$

Testing hypotheses

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

	One sample z		One sample t
Test statistic	$z_{\bar{X}} = \dfrac{\bar{X} - \mu_{\bar{X}}}{\sigma_{\bar{X}}}$	different	$t = \dfrac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}}$
Diff. Expected by chance	$\sigma_{\bar{X}} = \dfrac{\sigma}{\sqrt{n}}$	Standard error	
			don't know this, so need to estimate it

Testing hypotheses

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

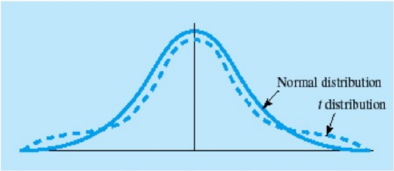
	One sample z	One sample t
Test statistic	$z_{\bar{X}} = \dfrac{\bar{X} - \mu_{\bar{X}}}{\sigma_{\bar{X}}}$	different $t = \dfrac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}}$
Diff. Expected by chance	$\sigma_{\bar{X}} = \dfrac{\sigma}{\sqrt{n}}$ Standard error	$s_{\bar{X}} = \dfrac{s}{\sqrt{n}}$ Estimated standard error
	don't know this, so need to estimate it	Degrees of freedom $df = n - 1$

One-sample t-test

- The t-statistic distribution (a transformation of the distribution of sample means transformed)
  - Varies in shape according to the degrees of freedom

- New table: the t-table

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604
5	1,476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
:	:	:	:	:	:
15	1.341	1.753	2.131	2.602	2.947
:	:	:	:	:	:



One-sample t-test

- The t-statistic distribution (a transformation of the distribution of sample means transformed)
  - To reject the H_0, you want a computed test statistics that is large
    - The alpha level gives us the decision criterion
    - New table: the t-table

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
1	3.078	6.314	12.706	31.821	63.657
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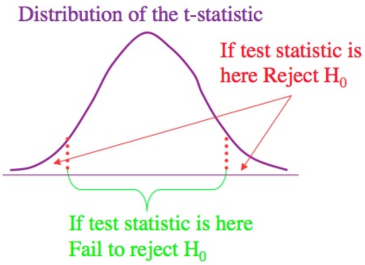

One-sample t-test

α - level

- New table: the t-table

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:	:	:	:	:	:
15	1.341	1.753	2.131	2.602	2.947
:	:	:	:	:	:

One tailed
- or -
Two-tailed

Degrees of freedom
df

Critical values of t
t_{crit}

One-sample t-test

- What is the t_{crit} for a two-tailed hypothesis test with a sample size of $n = 6$ and an α-level of 0.05?

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
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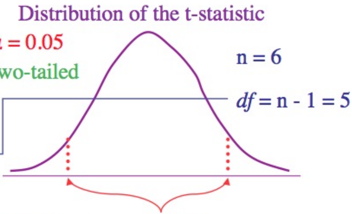
5	1.476	2.015	2.571	3.365	4.032
6	1.440	1.943	2.447	3.143	3.707
:	:	:	:	:	:
15	1.341	1.753	2.131	2.602	2.947
:	:	:	:	:	:

$\alpha = 0.05$

Two-tailed



$t_{crit} = \pm 2.571$

One-sample t-test

- What is the t_{crit} for a one-tailed hypothesis test with a sample size of n = 6 and an α-level of 0.05?

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
1	3.078	6.314	12.706	31.821	63.657
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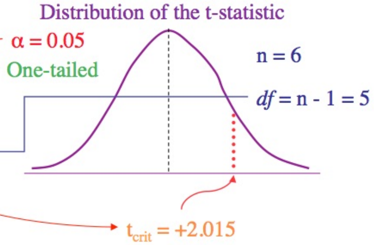


One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, $\boxed{s = 8}$ memory errors.

Do know s

- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

Don't know σ

One-sample *t*-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

- Step 1: State your hypotheses

H_0: the memory treatment sample are the same (or worse) as those in the population of memory patients.

$$\mu_{Treatment} \geq \mu_{pop} = 60$$

H_A: they perform better than those in the population of memory patients

$$\mu_{Treatment} < \mu_{pop} = 60$$

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\overline{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$
H_A: $\mu_{Treatment} < \mu_{pop} = 60$

- Step 2: Set your decision criteria

One -tailed $\alpha = 0.05$

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$

H_A: $\mu_{Treatment} < \mu_{pop} = 60$

- Step 2: Set your decision criteria

One -tailed $\alpha = 0.05$

One-sample *t*-test

An example: **One sample t-test**

Memory experiment example:

- We give a $n = 16$ memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, $s = 8$ memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$
H_A: $\mu_{Treatment} < \mu_{pop} = 60$
One -tailed $\alpha = 0.05$

- Step 3: Collect your data

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{\text{Treatment}} \geq \mu_{\text{pop}} = 60$
H_A: $\mu_{\text{Treatment}} < \mu_{\text{pop}} = 60$
One -tailed $\alpha = 0.05$

- Step 4: Compute yo statistics

$$s_{\bar{X}} = \frac{s}{\sqrt{n}} = \frac{8}{\sqrt{16}}$$

$$t = \frac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}} = \frac{55 - 60}{\left(8/\sqrt{16}\right)}$$

$$= -2.5$$

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$
H_A: $\mu_{Treatment} < \mu_{pop} = 60$

One -tailed $\alpha = 0.05$

$t = -2.5$

- Step 4: Compute your test statistics

$$df = n - 1 = 16 - 1 = 15$$

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\bar{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$
H_A: $\mu_{Treatment} < \mu_{pop} = 60$

One -tailed $\alpha = 0.05$

$t(15) = -2.5$ $df = 15$

- Step 5: Make a decision about your null hypothesis

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
:	:	:	:	:	:
15	1.341	1.753	2.131	2.602	2.947
:	:	:	:	:	:

$t_{crit} = -1.753$

One-sample t-test

An example: **One sample t-test**

Memory experiment example:

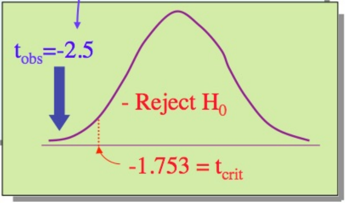
- We give a n = 16 memory patients a memory improvement treatment.
- After the treatment they have an average score of $\overline{X} = 55$, s = 8 memory errors.
- How do they compare to the general population of memory patients who have a distribution of memory errors that is Normal, $\mu = 60$?

H_0: $\mu_{Treatment} \geq \mu_{pop} = 60$
H_A: $\mu_{Treatment} < \mu_{pop} = 60$

One -tailed $\alpha = 0.05$

$t(15) = -2.5$ $df = 15$

- Step 5: Make a decision about your null hypothesis



Dependent Means t-test

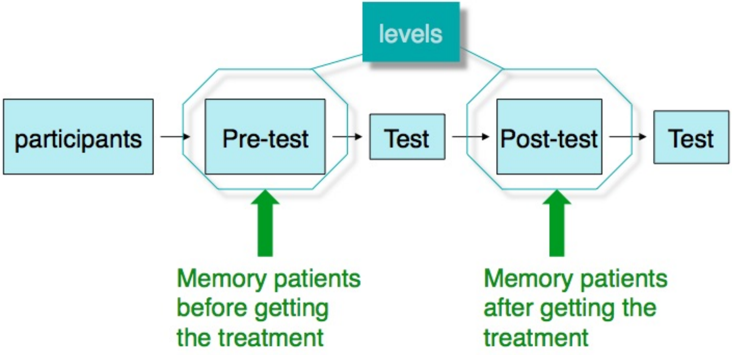
The dependent means t-test can be used when:

- 1 sample
- Two scores per subject

$$t = \frac{\overline{D} - \mu_{\overline{D}}}{s_{\overline{D}}}$$

Dependent Means t-test

- Dependent means: within-subjects factor
  - Sometimes called "repeated measures" design
  - 2-levels, All of the participants are in both levels of the IV



Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

- Difference scores
  - For each person, subtract one score from the other
  - Carry out hypothesis testing with the difference scores
- H_0 Population of difference scores has a mean = 0

What are all of these "D' s" referring to?

Mean of the ***differences***	$t = \dfrac{\overline{D} - \mu_{\overline{D}}}{s_{\overline{D}}}$	Test statistic
Estimated standard error of the ***differences***	$s_{\overline{D}} = \dfrac{s_D}{\sqrt{n_D}}$	Diff. Expected by chance
Number of ***difference*** scores	$df = n_D - 1$	

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

One-sample t

$$t = \frac{\bar{X} - \mu_{\bar{X}}}{s_{\bar{X}}}$$

Related samples t

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}}$$

Difference between
Observed (sample) means

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

One-sample t

$$t = \frac{\overline{X} - \mu_{\overline{X}}}{s_{\overline{X}}}$$

Hypothesized population means
- from the Null hypothesis

Related samples t

$$t = \frac{\overline{D} - \mu_{\overline{D}}}{s_{\overline{D}}}$$

Hypothesized difference between Population means
- from the Null hypothesis

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

One-sample t

$$t = \frac{\overline{X} - \mu_{\overline{X}}}{s_{\overline{X}}}$$

Related samples t

$$t = \frac{\overline{D} - \mu_{\overline{D}}}{s_{\overline{D}}}$$

Hypothesized difference between Population means

- from the Null hypothesis

H_0: Memory performance by the treatment group is equal to memory performance by the no treatment group.

So: $(\mu_A - \mu_B) = 0$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

(Pre-test) - (Post-test)

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores
1	45	43	2
2	55	49	6
3	40	35	5
4	60	51	9
			22

$$t = \frac{\overline{D} - \mu_{\overline{D}}}{s_{\overline{D}}}$$

H_0: There is no difference between pre-test and post-test

$\mu_D = 0$

H_A: There is a difference between pre-test and post-test

$\mu_D \neq 0$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

(Pre-test) - (Post-test)

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores
1	45	43	2
2	55	49	6
3	40	35	5
4	60	51	9
			22

$$n_D = 4 \qquad \frac{\sum D}{n_D} = \bar{D} = 5.5$$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}}$$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

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3	40	35	5
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			22

$n_D = 4$ $\quad \bar{D} = 5.5$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{s_{\bar{D}}}$$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
1	45	43	2- 5.5 =	-3.5	12.25
2	55	49	6- 5.5 =	0.5	0.25
3	40	35	5- 5.5 =	-0.5	0.25
4	60	51	9- 5.5 =	3.5	12.25

$n_D = 4$

22

$\bar{D} = 5.5$

$25 = SS_D$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{s_{\bar{D}}}$$

$$s_{\bar{D}} = \frac{s_D}{\sqrt{n_D}}$$

$$s_D = \sqrt{\frac{SS_D}{n_D - 1}} = \sqrt{\frac{25}{4-1}} = 2.9$$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D's" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
1	45	43	2	-3.5	12.25
2	55	49	6	0.5	0.25
3	40	35	5	-0.5	0.25
4	60	51	9	3.5	12.25
			22		$25 = SS_D$

$n_D = 4$

$\bar{D} = 5.5$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{s_{\bar{D}}}$$

$$s_{\bar{D}} = \frac{s_D}{\sqrt{n_D}}$$

$$s_D = \sqrt{\frac{SS_D}{n_D - 1}} = \sqrt{\frac{25}{4-1}} = 2.9$$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
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3	40	35	5	-0.5	0.25
4	60	51	9	3.5	12.25
$n_D = 4$			22 $\bar{D} = 5.5$		$25 = SS_D$ $2.9 = s_D$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{s_{\bar{D}}}$$

$$s_{\bar{D}} = \frac{s_D}{\sqrt{n_D}} = \frac{2.9}{\sqrt{4}} = 1.45$$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
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3	40	35	5	-0.5	0.25
4	60	51	9	3.5	12.25

$n_D = 4$

22

$\bar{D} = 5.5$

$25 = SS_D$

$2.9 = s_D$

$1.45 = s_{\bar{D}}$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{1.45}$$

?

Think back to the null hypotheses

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
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2	55	49	6	0.5	0.25
3	40	35	5	-0.5	0.25
4	60	51	9	3.5	12.25

$n_D = 4$

22

$\bar{D} = 5.5$

$25 = SS_D$

$2.9 = s_D$

$1.45 = s_{\bar{D}}$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - \mu_{\bar{D}}}{1.45}$$

H_0: Memory performance at the post-test are equal to memory performance at the pre-test.

$\mu_{\bar{D}} = 0$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
1	45	43	2	-3.5	12.25
2	55	49	6	0.5	0.25
3	40	35	5	-0.5	0.25
4	60	51	9	3.5	12.25
			22		$25 = SS_D$

$n_D = 4$

$\bar{D} = 5.5$

$2.9 = s_D$

$1.45 = s_{\bar{D}}$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - 0}{1.45}$$

This is our $t_{obs} = 3.8$

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
1	45	43	2	-3.5	12.25
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			22		$25 = SS_D$

$n_D = 4$

$\bar{D} = 5.5$

$2.9 = s_D$

$1.45 = s_{\bar{D}}$

$df = n_D - 1$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - 0}{1.45}$$

$t_{obs} = 3.8$

$t_{crit} = \pm 3.18$

$\alpha = 0.05$ Two-tailed

	Proportion in one tail				
	0.10	0.05	0.025	0.01	0.005
	Proportion in two tails				
df	0.20	0.10	0.05	0.02	0.01
1	3.078	6.314	12.706	31.821	63.657
2	1.886	2.920	4.303	6.965	9.925
3	1.638	2.353	3.182	4.541	5.841
4	1.533	2.132	2.776	3.747	4.604

Dependent Means t-test

$$\text{test statistic} = \frac{\text{observed difference}}{\text{difference expected by chance}}$$

What are all of these "D' s" referring to?

Person	Pre-test	Post-test	Difference scores	$D - \bar{D}$	$(D - \bar{D})^2$
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$\bar{D} = 5.5$

$2.9 = s_D$

$1.45 = s_{\bar{D}}$

$df = n_D - 1$

$$t = \frac{\bar{D} - \mu_{\bar{D}}}{s_{\bar{D}}} = \frac{5.5 - 0}{1.45}$$

$t_{obs} = 3.8$

$\alpha = 0.05$ Two-tailed $t_{crit} = \pm 3.18$