Factorial ANOVA
(part 1)

Lecture 16

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Woah, you've achieved a lot!

- One-way ANOVA

Source	SS	df	MS	F
Between	60	3		
Within	200	50		
Total				

Our goal is to get to the **last column** (our F-ratio)

- Family-Wise Error Rate
- Follow-up tests

You've already learned some of the most common statistical tests used in real life!

You have tools to answer most common questions. But not these:

You helped your lab to determine the one best treatment of ADHD from 3 possible medications. It’s adderall.

**But now imagine someone asks you:
Would you recommend Adderall to every person with ADHD?**

What if some people have underlying heart conditions that make stimulants like Adderall risky?

Hm... we need another factor

TODAY'S PLAN

01

The Factorial Design

02

Main Effects & Interactions

03

Eyeball & Table Method

04

Wrap Up

Learning objectives

- **Differentiate** one-way and factorial ANOVAs.
- Describe the **structure** of a factorial research design, especially a **two-factor design**, using the terms factor and level.
- Define and explain the concepts of **main effects** and **interactions** in factorial ANOVAs.
- **Interpret graphs** and **tables** to identify patterns that reflect **main effects, interactions, or both**.

01

The Factorial Design

Recap: One-way ANOVA

Gathers

Molly Tea

Tiger Sugar

Factor

Aka independent variable (IV): Bubble tea shops in Chicago

Levels are <u>options</u> of the factor

Levels

3 levels in our example (aka, 3 shops we are comparing)

Dependent variable (DV): Wait time

What is Factorial ANOVA?

Factorial ANOVA (often called X-Way ANOVA) examines the effect of **two or more** independent variables (factors) on a single dependent variable.

Our bubble tea example had only one factor (IV) – bubble tea shops in Chicago. This one factor has 3 levels.

But sometimes, having one factor is not enough to answer our question – like the example about using Adderall without considering underlying heart conditions.

Remember: the statistical tests we're learning are *just tools*.

We don't use them because they exist—we use them because they help us answer real questions.
And when one tool no longer gets the job done, we develop new ones.

One-Way ANOVA works great—until we realize that a single factor isn’t enough to explain what’s happening.
That’s when we turn to Factorial ANOVA.
It wasn’t invented just for fun—it was invented to solve a real problem that One-Way ANOVA couldn’t.

So as we move forward, think about each new method not as “just another thing to memorize,” but as a response to a limitation, a way to ask smarter questions about the world.

2 x 2 Design

(DV: ADHD symptoms)

Factor B: Heart Condition	Factor A: ADHD medications — Stimulant	Factor A: ADHD medications — Non-Stimulant
Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**

There are **4 cells** in this example

2 x 2 Design

(DV: energy levels)

Factor A: Personality

Factor B: Chronotype

	Introvert	Extravert
Early Bird	**Introverts** who are **early birds**	**Extraverts** who are **early birds**
Night Owl	**Introverts** who are **night owls**	**Extraverts** who are **night owls**

There are **4 cells** in this example

2 x 3 Design

(DV: productivity)

Factor A: Study Environment

Factor B: Time of Day

	Cafe	Library
Morning	Students who study at **cafe** in **morning**	Students who study at **library** in **morning**
Afternoon	Students who study at **cafe** in **afternoon**	Students who study at **library** in **afternoon**
Evening	Students who study at **cafe** in **evening**	Students who study at **library** in **evening**

A quick note:

2 x 2 Design
(DV: ADHD symptoms)

2 x 3 Design
(DV: productivity)

If you see two numbers multiplied (e.g., 2×3), that means there are 2 **factors**. Something like 2×3×2 means 3 **factors**. Each number shows how many **levels** are in that factor—so 2×3 means the first factor has 2 **levels**, the second has 3.

While factorial ANOVAs can include more than 2 factors, most of the time we focus on 2-factor designs. That's usually what people mean when they say "Factorial ANOVA."

In other words

2 x 2 Design
(DV: ADHD symptoms)

2 x 3 Design
(DV: productivity)

Both called **two-way** ANOVA

Because there are **2 factors**

The X-way doesn't describe how many levels are in each factor.

As you notice, factorial ANOVA can have 2, or more than 2 factors.

Unlike One-Way ANOVA, where the single factor must have more than 2 levels (otherwise we'd just use a t-test),
each factor in a factorial ANOVA can have as few as two levels.

Two levels per factor is totally valid—you just need at least two factors to call it a factorial design.

In other words

One-way ANOVA → lower limit on the number of groups (>2)

Factorial ANOVA → lower limit on the number of levels within each factor (>=2)

<u>AND</u>

lower limit on the number of factors (>=2)

Knowledge Check

Read your scenario and **identify the number of factors** and the **number of levels** for each factor.

Determine the **factorial design** (e.g., 2 × 2, 3 × 4) and write it clearly.

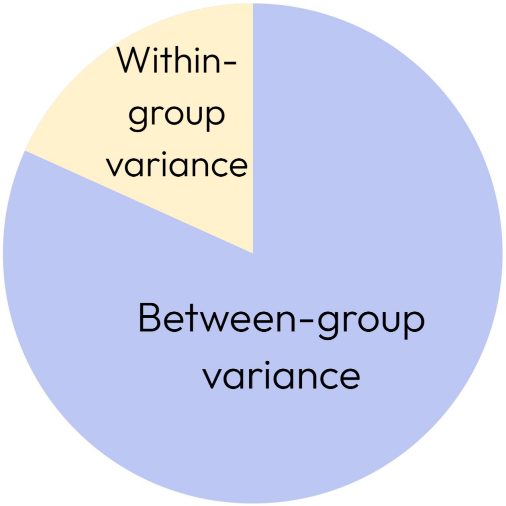
Draw the design on your notes (a table, matrix, or grid), with clear labels for each factor and its levels.

02

Main Effects & Interactions

Let’s approach the difference through this...

In one-way ANOVA we talked about “analyzing the variance” of the DV:



See how you can fit this factorial ANOVA into the variance pie:
Hint: “between” only had one factor before. What about now?

2 x 2 Design
(DV: ADHD symptoms)

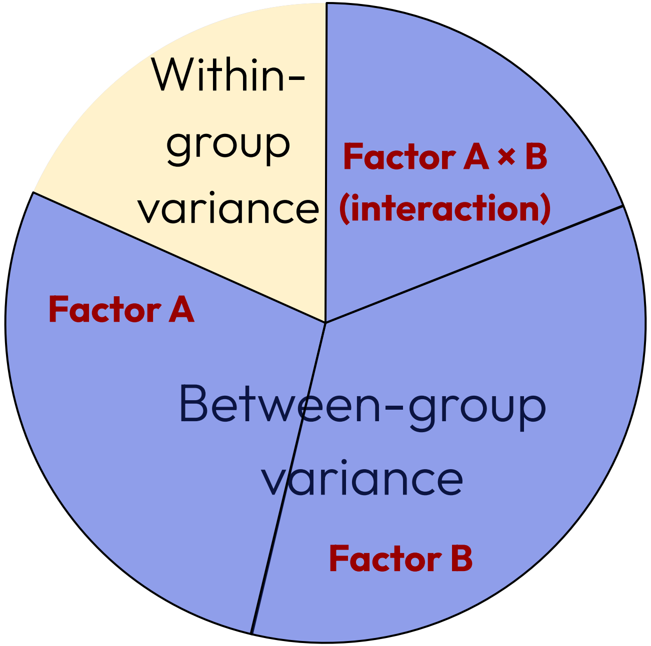
		Factor A: ADHD medications	
		Stimulant	Non-Stimulant
Factor B: Heart Condition	Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
	None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**

We just break up the between-group variance!

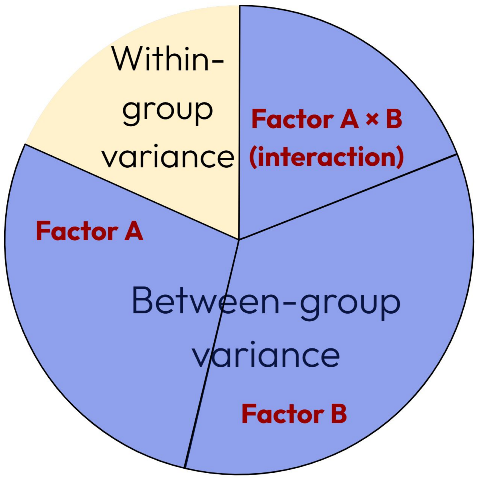
Both of the factors are
between-subjects / between groups!

2 x 2 Design
(DV: ADHD symptoms)

		Factor A: ADHD medications	
		Stimulant	Non-Stimulant
Factor B: Heart Condition	Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
	None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**



Terminology in stats lingo



Factor A: ADHD medications
Factor B: Heart condition

Main effect is the independent influence of one factor (IV) on the dependent variable (DV), at the average level of the other factor.

The **main effect of Factor A** means that:
Does the type of ADHD medication reduce symptoms, regardless of whether someone has a heart condition?

That’s what we mean when we say 'averaged across' the other factor.”

See if you can explain the main effect of Factor B in groups!

2 x 2 Design

(DV: ADHD symptoms)

Factor A: ADHD medications

Factor B: Heart Condition

Factor B: Heart Condition	Stimulant	Non-Stimulant
Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**

Does ADHD symptom severity differ between **stimulants** and **non-stimulants**?

2 x 2 Design

(DV: ADHD symptoms)

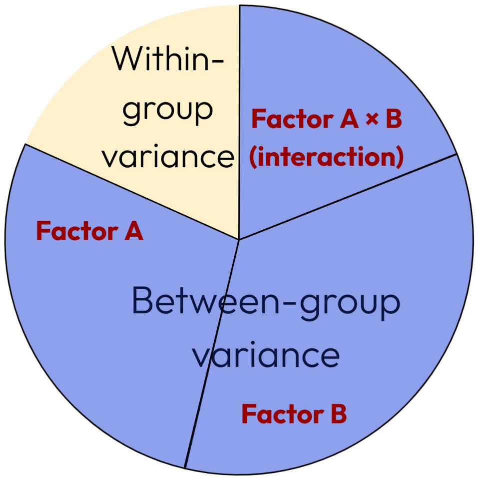
Factor A: ADHD medications

Factor B: Heart Condition

	Stimulant	Non-Stimulant
Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**

Does ADHD symptom severity differ between those who **have heart** and **those who don't**?

Terminology in stats lingo



Factor A: ADHD medications
Factor B: Heart condition

An **interaction** occurs when when the effect of one factor **depends on** the level of the other factor.

- Stimulants reduce ADHD symptoms more than non-stimulants. (main effect of Factor A)
- Heart condition status doesn't change ADHD symptom severity on its own. (No main effect of Factor B)
- But: Stimulants work well only for people without heart conditions, and don't help (or may even harm) those with heart conditions. (**interaction**)

The effect of medication depends on whether someone has a heart condition.

Which medication would you recommend to treat ADHD?

It depends...

So which medication would you recommend to someone with a heart condition?

What about for someone without a heart condition?

Let’s assume for a second that there isn’t an interaction…

Which medication would you recommend to treat ADHD?

In this case, the outcome only depends on one factor, most likely the ADHD med type

So you will make your recommendation based on which med type is more effective, you don’t have to worry about whether someone has heart conditions

03

Eyeball & Table Method

Finding Main Effects & Interactions

How do we know if we have a main effect or an interaction?

We conduct the factorial ANOVA and look at the *p*-value that correspond to each factor & the interaction!

Each time we look at a *p*-value, we're essentially performing a little hypothesis test—just like in other NHST procedures.

We will leave the calculation to the next class. For now, we will talk about how to tell **visually** whether there are main effects or interactions.

Finding Main Effects & Interactions

“Eyeball” Method

We can often spot main effects and interactions by **visually analyzing graphs**. We will learn some tricks for this today.

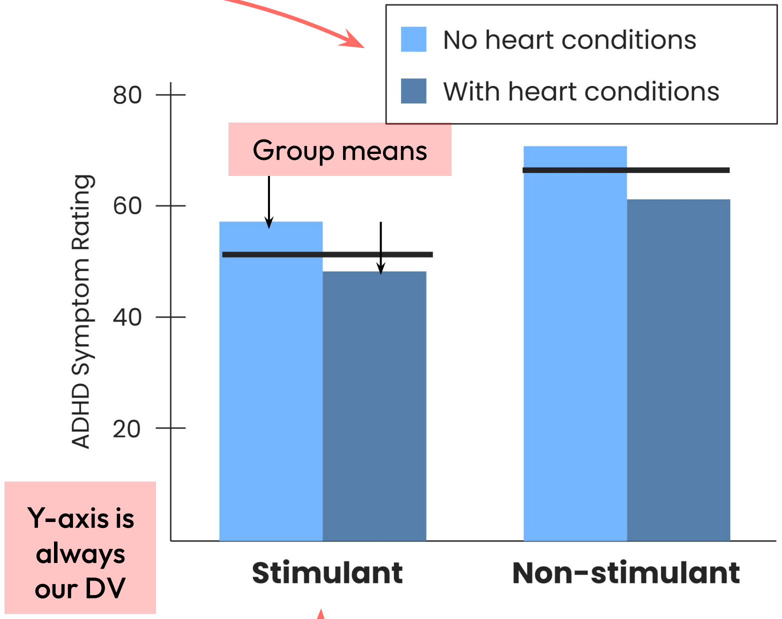
“Table” Method

Tables can give us **more precise information** and can also help us decide whether there are main effects and/or interactions.

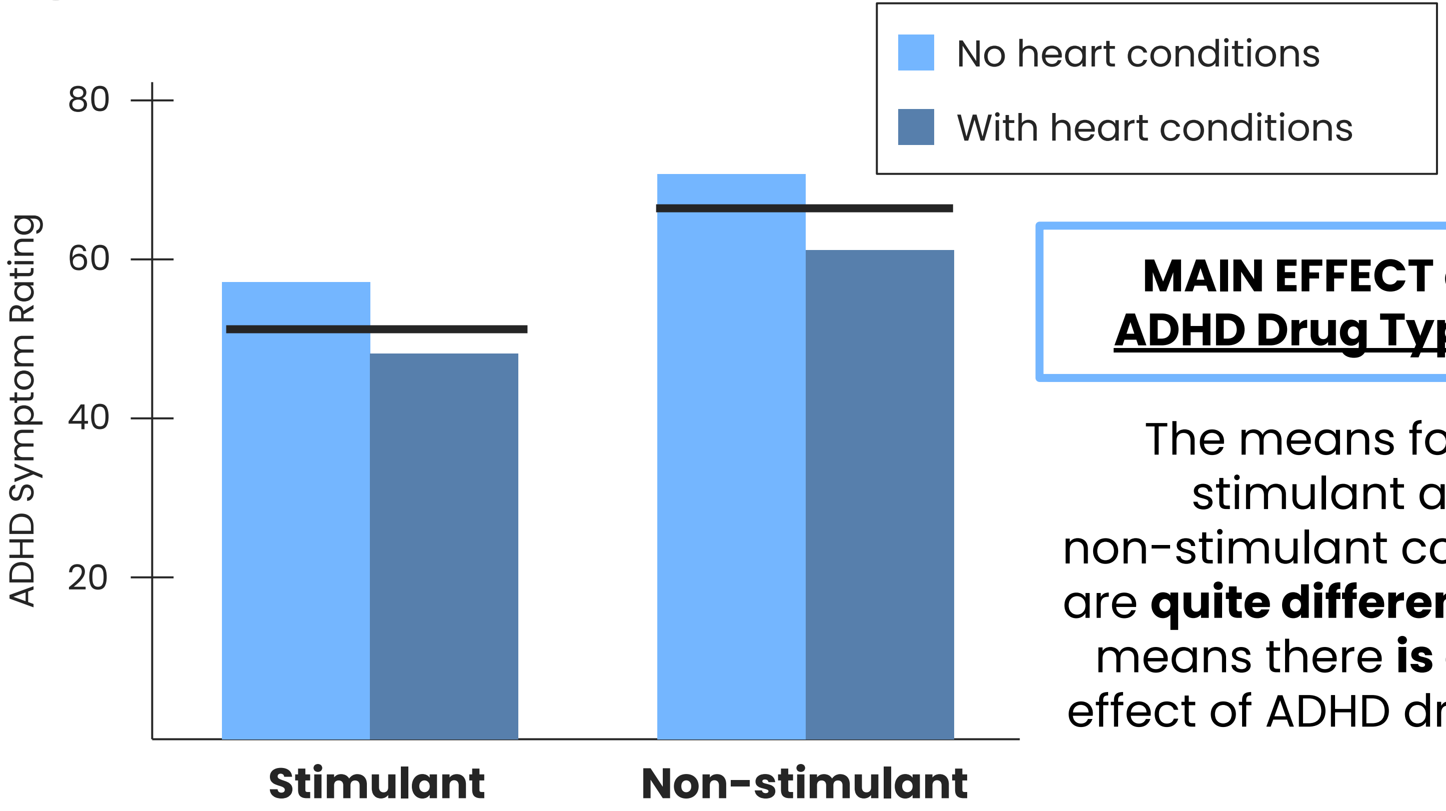
First, plotting the factorial ANOVA

2 x 2 Design
(DV: ADHD symptoms)

		Factor A: ADHD medications	
		Stimulant	Non-Stimulant
Factor B: Heart Condition	Present	**Has heart condition** and **on stimulant**	**Has heart condition** and **not on stimulant**
	None	**No heart condition** and **on stimulant**	**No heart condition** and **not on stimulant**



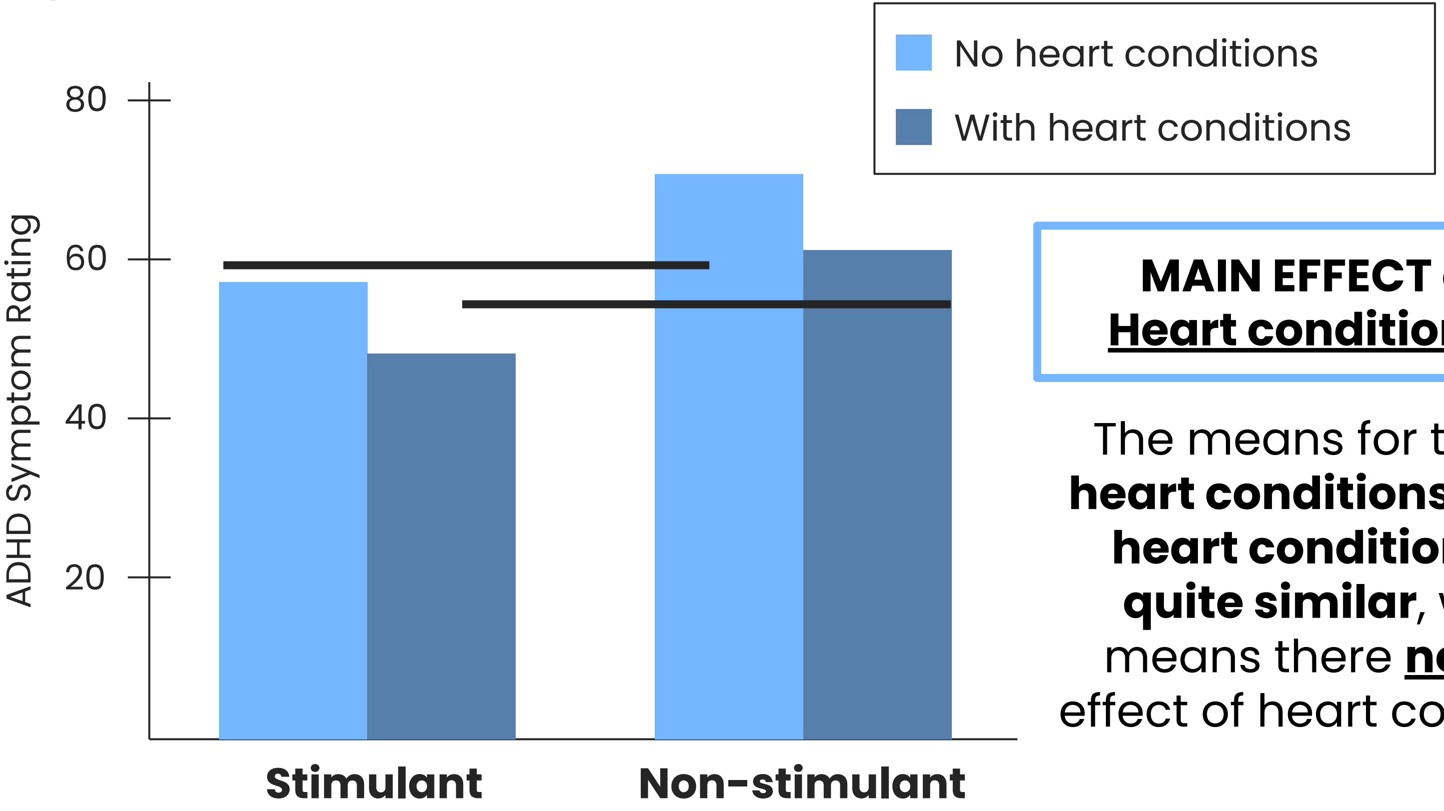
“Eyeball” Method (example 1)



MAIN EFFECT of
<u>ADHD Drug Type</u>?

The means for the stimulant and non-stimulant conditions are **quite different**, which means there **is** a main effect of ADHD drug type.

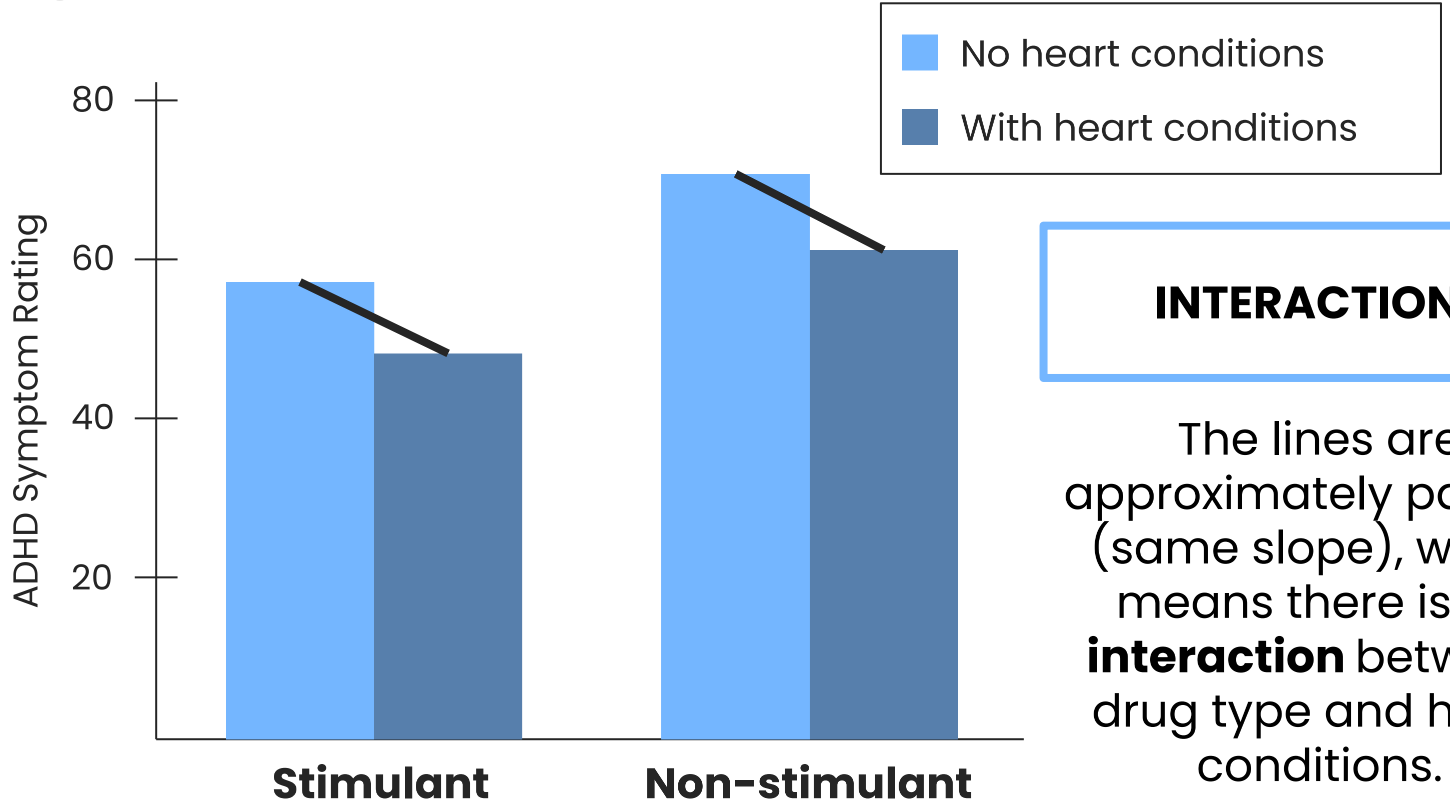
"Eyeball" Method (example 1)



MAIN EFFECT of <u>Heart conditions</u>?

The means for the **has heart conditions** and **no heart conditions** are **quite similar**, which means there **<u>no</u>** main effect of heart conditions.

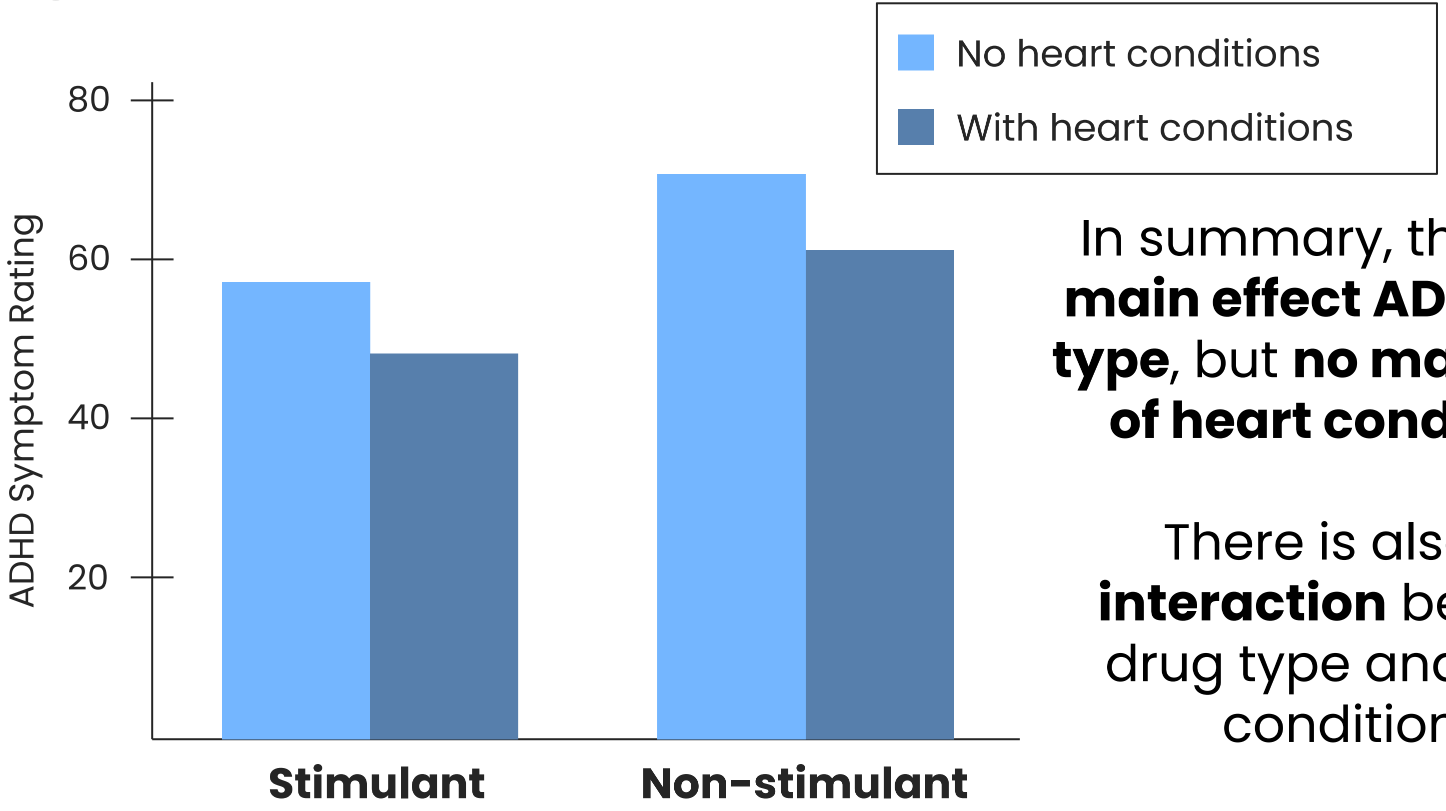
“Eyeball” Method (example 1)



INTERACTION?

The lines are approximately parallel (same slope), which means there is **no interaction** between drug type and heart conditions.

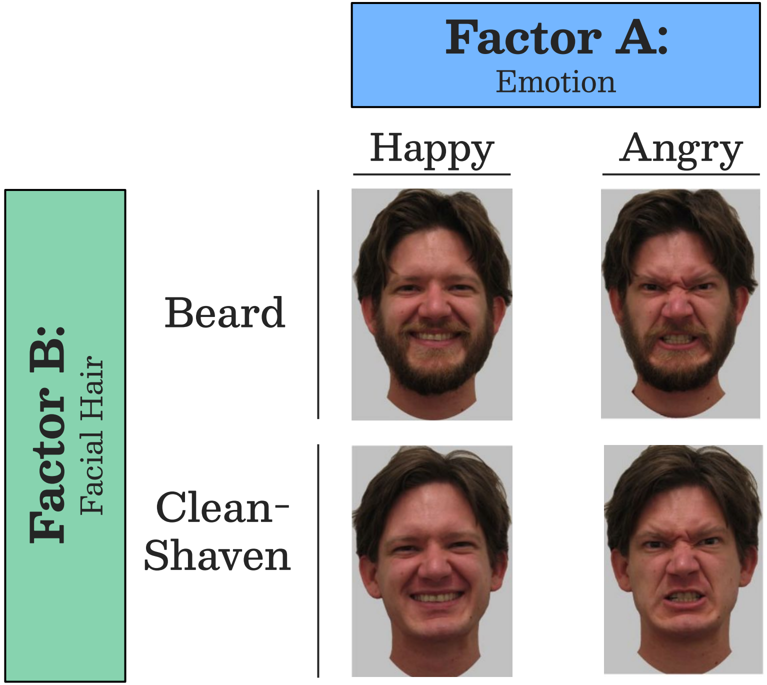
“Eyeball” Method (example 1)



In summary, there is a **main effect ADHD drug type**, but **no main effect of heart conditions**.

There is also **no interaction** between drug type and heart conditions.

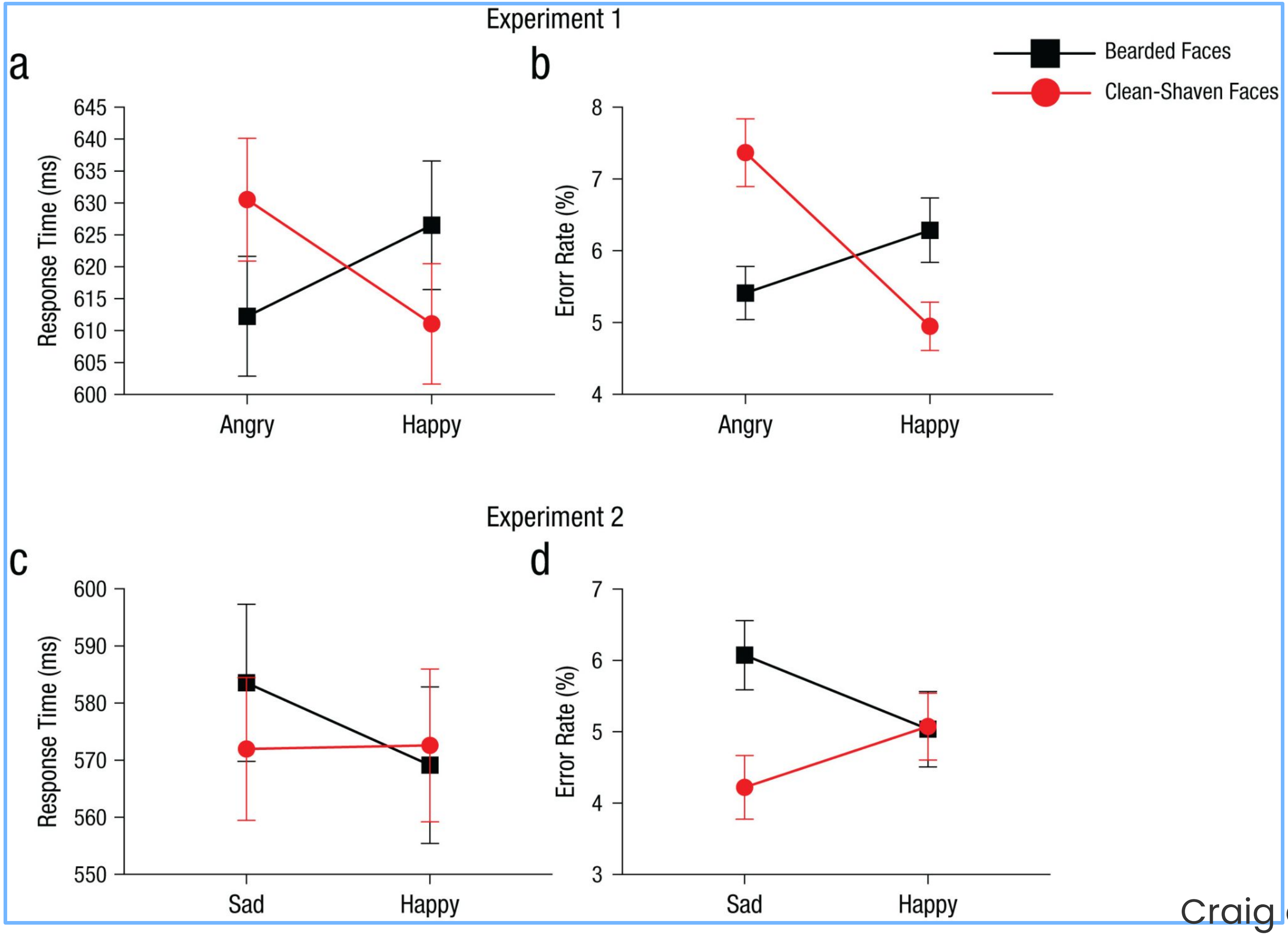
Research Example



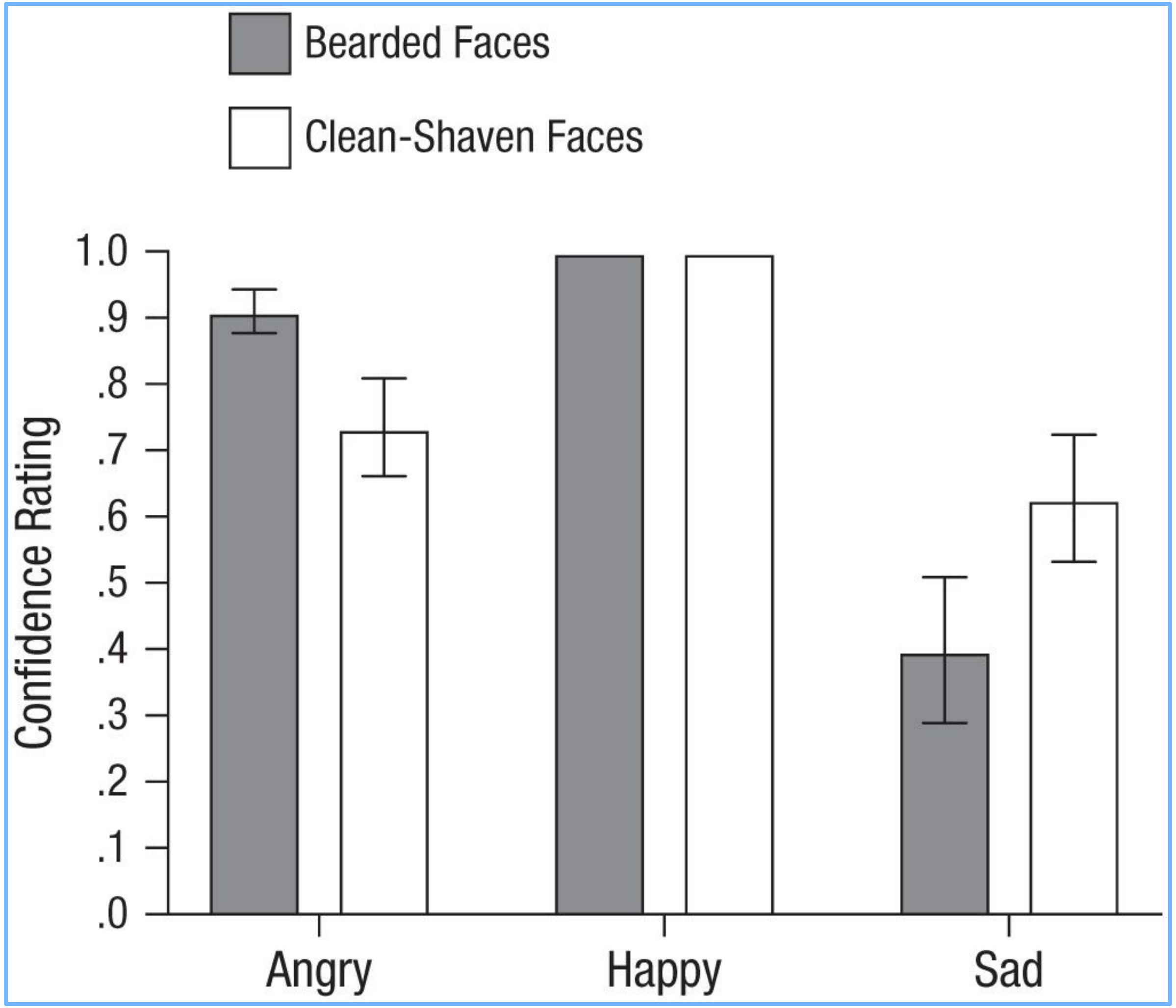
Craig et al. (2019) investigated whether beards enhance recognition of threatening expressions like anger.

They presented participants with photographs of the same men bearded and clean-shaven posing as either happy or angry.

Participants were asked to categorize each face as either 'happy' or 'angry' as quickly and accurately as possible.

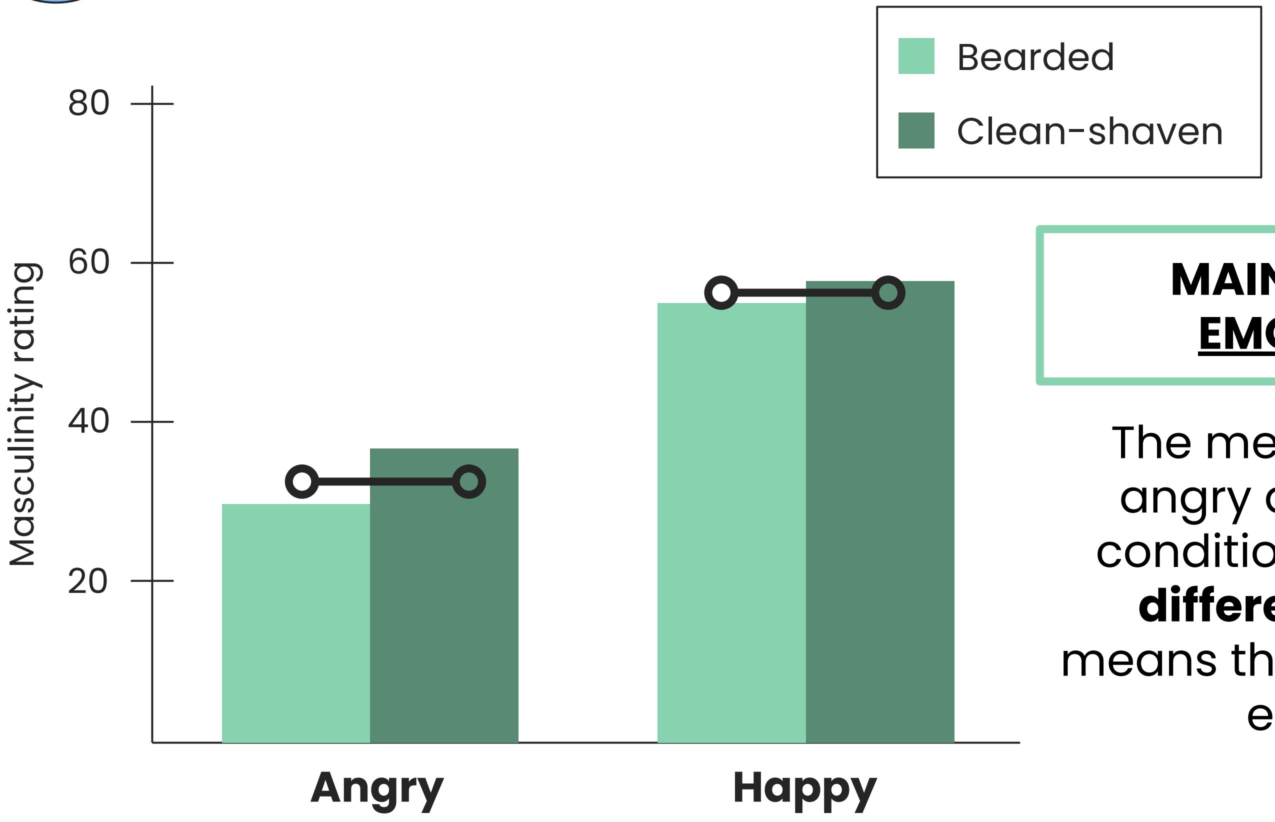


Craig et al. (2019)



Craig et al. (2019)

“Eyeball” Method (example 2)



MAIN EFFECT
<u>EMOTION</u>?

The means for the angry and happy conditions are **very different**, which means there **is** a main effect.

“Eyeball” Method (example 2)

MAIN EFFECT
FACIAL HAIR?

The means for the bearded and clean-shaven conditions are **similar** which means there is **not** likely main effect.

“Eyeball” Method (example 2)

INTERACTION?

The lines are approximately parallel (same slope), which means there is **no interaction**.

“Eyeball” Method (example 2)

In summary, there is a **main effect of emotion**, but **no main effect of facial hair**. There is also **no interaction**.

“Eyeball” Method (example 3)

MAIN EFFECT
<u>EMOTION</u>?

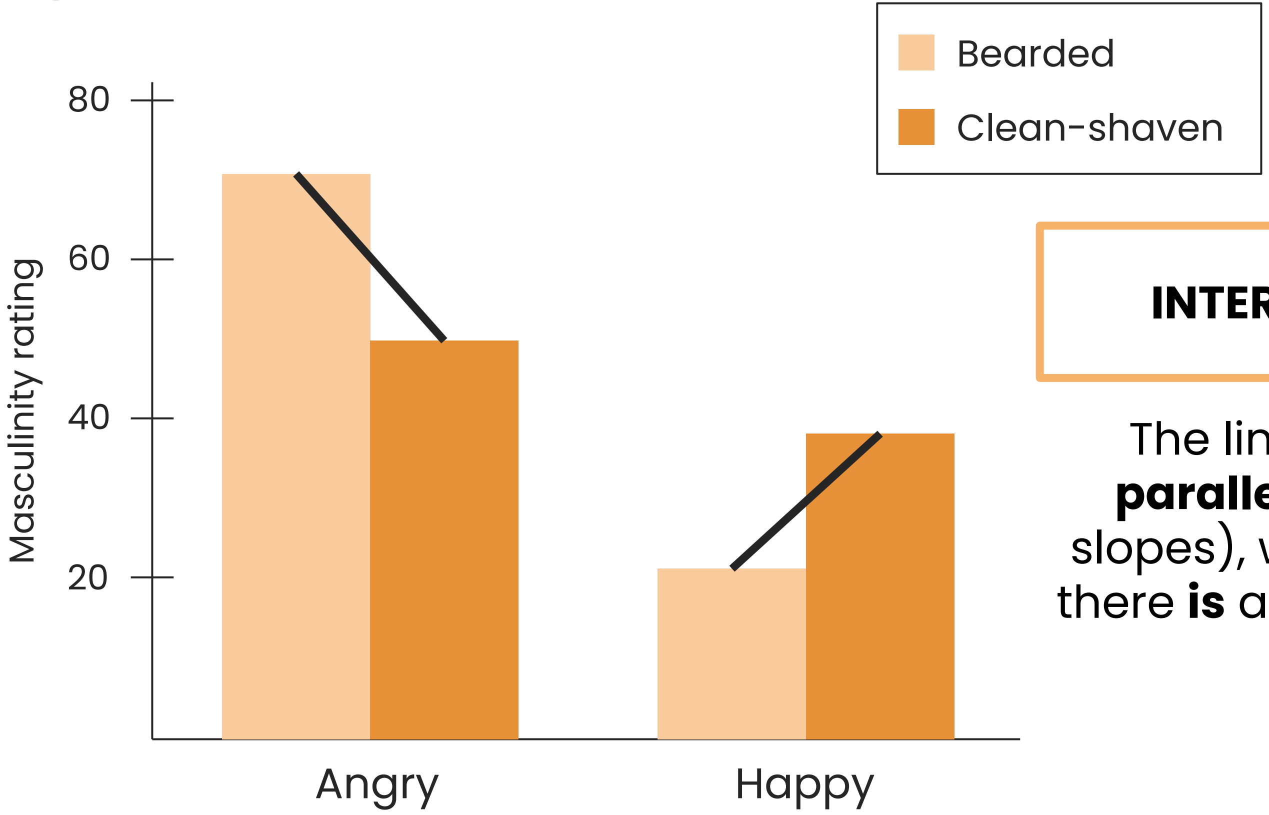
The means for the angry and happy conditions are **very different**, which means there **is** a main effect.

“Eyeball” Method (example 3)

MAIN EFFECT
FACIAL HAIR?

The means for the bearded and clean-shaven conditions are **similar** which means there is **not** likely main effect.

“Eyeball” Method (example 3)



INTERACTION?

The lines are **not parallel** (different slopes), which means there **is** an **interaction**.

“Eyeball” Method (example 3)

In summary, there is a **main effect of emotion**, but **no main effect of facial hair**. There is an **interaction**.

ICA 16

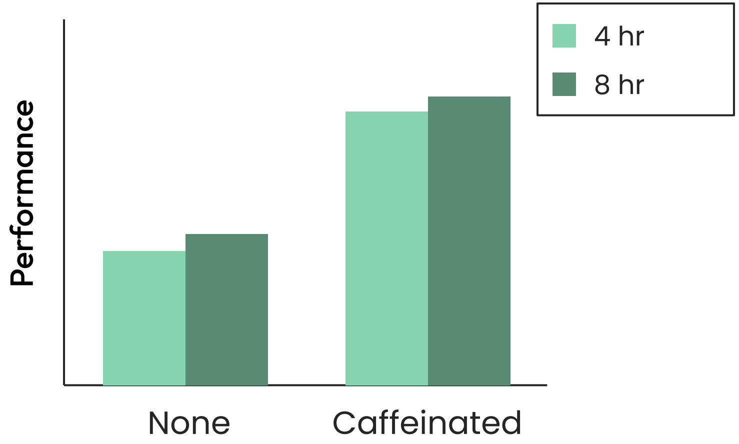
Researchers examine whether the effect of **caffeine** on **cognitive performance** depends on how much **sleep** someone had the night before.

IVs: **Caffeine**: None vs. Caffeinated;

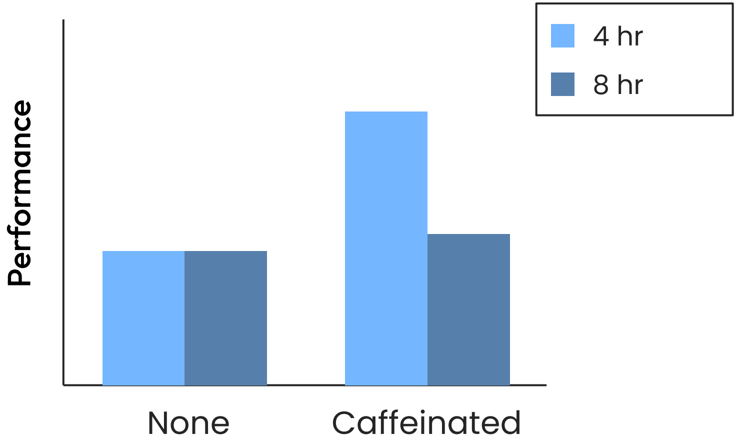
Sleep Quality: Well-rested (8h) vs. Sleep-deprived (4h)

DV: **Performance** on a sustained attention task (0–100)

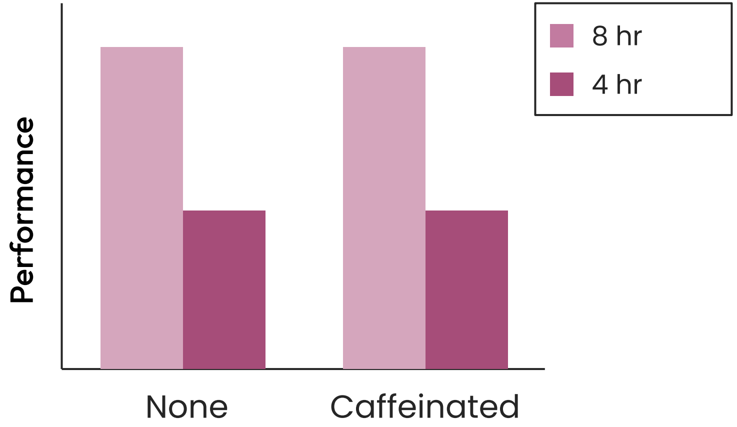
#1


Performance
4 hr
8 hr
None
Caffeinated

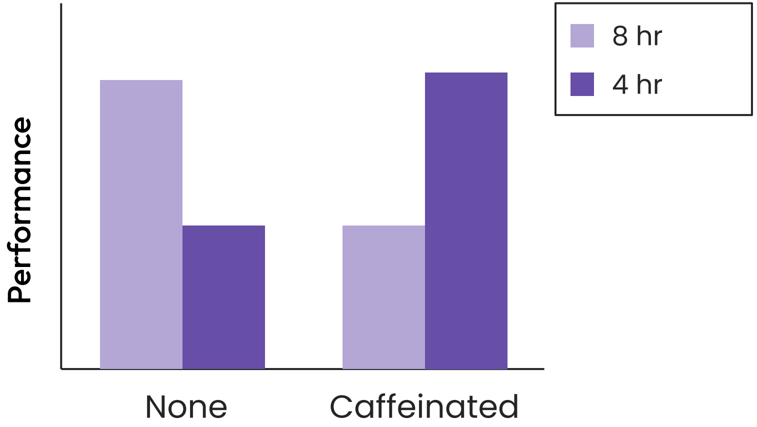
#2


Performance
4 hr
8 hr
None
Caffeinated

#3


Performance
8 hr
4 hr
None
Caffeinated

#4


Performance
8 hr
4 hr
None
Caffeinated

"Table" Method (main effects)

For main effects, we **compare the difference in the marginal means** for both factors to see if it is *more than the error*.

		Factor A: Treatment		Marginal Means
		CBT	Mindful.	
Factor B: Modality	In-person	30	50	
	Online	40	60	
Marginal Means				

Error: 15

"Table" Method (main effects)

		Factor A: Treatment		Marginal Means
		CBT	Mindful.	
Factor B: Modality	In-person	30	50	**40**
	Online	40	60	**50**
Marginal Means		**35**	**55**	

Error: 15

10

no main effect of **modality**

20

a main effect of **treatment**

“Table” Method (interaction)

If the **change** in the cell means is **about the same**, then there is **no interaction**.

		Factor A: Treatment			Marginal Means
		CBT		Mindful.	
Factor B: Modality	In-person	30	**+20**	50	40
	Online	40	**+20**	60	50
Marginal Means		35		55	

Error: 15

“Table” Method (example)

Are there any **main effects** or **interactions**?

		Factor A: Treatment		Marginal Means
		CBT	Mindful.	
Factor B: Modality	In-person	5	9	
	Online	7	4	
Marginal Means				

Error: 1.0

“Table” Method (example)

Are there any **main effects** or **interactions**?

		Factor A: Treatment		Marginal Means
		CBT	Mindful.	
Factor B: Modality	In-person	5	9	**7**
	Online	7	4	**5.5**
Marginal Means		**6**	**6.5**	

Error: 1.0

“Table” Method (example)

Are there any **main effects** or **interactions**?

An interaction between modality and treatment

		Factor A: Treatment			Marginal Means
		CBT		Mindful.	
Factor B: Modality	In-person	5	+4	9	**7**
	Online	7	-3	4	**5.5**
Marginal Means		**6**		**6.5**	

1.5
a main effect of **modality**

Error: 1.0

0.5

no main effect of **treatment**

Interactions change your entire story

2 x 2 Design
(DV: ADHD symptoms)

		Factor A: ADHD medications	
		Stimulant	Non-Stimulant
Factor B: Heart Condition	Present	**Risky!**	Generally safe
	None	Generally safe	Generally safe

In our ADHD example, stimulants may show a main effect of **reducing** symptoms overall. But the interaction tells us something more important: Stimulants **help** one group (no heart condition) but may **worsen** symptoms or have no effect for the other group (with heart condition).

IF there is an interaction: You have to interpret the main effect in light of the interaction—because the effect isn't the same across groups.

04

Wrap Up

Key Takeaways

- Factorial ANOVA
    - Terms (levels, factors, 2x2, 2x3...)
    - WHY?
    - Main effect & interaction
    - Partitioning our variance pie into main effect & interaction

- Spotting main effects & interaction using eyeball & table methods

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