PSYCH-434 Comprehensive Study Sheet

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LECTURE 1: Measurement, Validity, and Confounding

Key Concepts to Focus On:

1. Measurement in Psychology

- **Definition approaches:**
  - Conventional: "Numerical quantification of attributes for comparison"
  - Psychological: "Assignment of numerals to objects/events according to rules"
  - Metrological: "Process of experimentally obtaining quantity values attributable to a quantity"
- **Measurement challenges in surveys:**
  - Ambiguity in interpretation
  - Social desirability bias
  - Mood effects on reliability
  - Limited scale range
  - Cultural differences in meanings and constructs

2. Validity Types

- **Content validity:** degree an instrument measures what it's intended to measure
- **Construct validity:** whether the construct is accurately defined and operationalised
- **Criterion validity:** whether an instrument accurately predicts performance
- **Ecological validity:** whether an instrument reflects real-world situations and behaviour

3. Introduction to Confounding

- **Basic concept:** when the relationship between variables is influenced by a third variable

- **Example:** age might cause both marriage and happiness, creating a spurious association
- **Collider bias:** when controlling for a common effect creates a spurious association
- Example: income as a collider between happiness and marriage

4. Foundational Concepts of Validity in Research

- **Internal validity:** degree to which a study demonstrates causal relationships free of confounding
- **External validity:** extent to which findings generalise to other situations, people, settings, and times

Focus Areas for the Test:

- Understand the different types of validity and be able to identify examples of each
- Recognise potential measurement issues, especially in cross-cultural contexts
- Identify basic confounding relationships in simple scenarios
- Understand the concept of collider bias at a basic level; try to think of an example

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LECTURE 2: Causal Diagrams - Five Elementary Structures

Key Concepts to Focus On:

1. The Five Elementary Causal Structures

- **Causality Absent:** No causal relationship between variables ($A \coprod B$)
- **Causality:** Direct causal effect ($A \to B$, $A \coprod B$)
- **Fork:** Common cause structure ($A \leftarrow C \to B$, $A \not\coprod B, A \coprod B|C$)
- **Chain:** Mediation structure ($A \to C \to B, A \not\coprod B, A \coprod B|C$)
- **Collider:** Common effect structure ($A \to C \leftarrow B, A \coprod B, A \not\coprod B|C$)

2. D-separation and Conditional Independence

- **D-connected:** Information flows between variables
- **D-separated:** Variables are conditionally independent
- **Notation:** $A \coprod B|C$ means A and B are independent given C

3. Four Rules of Confounding Control

- **Condition on Common Cause:** Control for variables that cause both exposure and outcome

- **Do Not Condition on a Mediator:** Avoid controlling for variables in the causal pathway
- **Do Not Condition on a Collider:** Avoid controlling for common effects
- **Proxy Rule:** Conditioning on a descendant is similar to conditioning on its parent

4. Time Indexing in Causal Diagrams

- **Left-to-right layout:** Reflects temporal sequence
- **Variable indexing:** X , X , X , etc. indicates chronological order
- **Uncertainty notation:** $X_{\varphi t}$ for ambiguous timing

Focus Areas for the Test:

- Identify the five elementary structures in causal diagrams
- Understand how d-separation helps identify causal effects
- Apply the rules of confounding control to simple scenarios
- Recognise the importance of time ordering in causal inference

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LECTURE 3: Causal Diagrams - The Structures of Confounding Bias

Key Concepts to Focus On:

1. Types of Confounding Bias

- **Fork bias (omitted variable bias):** Failing to control for common causes
- **Mediator bias:** Inappropriately controlling for variables in the causal pathway
- **Collider bias:** Inappropriately controlling for common effects
- **Proxy confounding:** Controlling for descendants of confounders or colliders

2. Regression and Causal Inference

- **Model fit vs. causal validity:** better statistical fit (R^2, AIC, BIC) does not imply correct causal inference
- **Simulation examples:** how controlling for mediators or colliders can bias causal effects
- **Coefficient interpretation:** regression coefficients have causal interpretations only under certain assumptions

3. M-bias

- **Structure:** a specific pattern where conditioning on a variable creates a backdoor path

- **Recognition:** importance of causal diagrams in identifying complex bias structures

4. Masked Relationships

- **Concept:** when variables have opposing effects that obscure relationships
- **Example:** variables with positive and negative effects cancelling each other out

Focus Areas for the Test:

- Identify different types of confounding bias in causal diagrams
- Understand why model fit statistics can be misleading for causal inference
- Recognise scenarios where conditioning on variables introduces bias
- Apply causal reasoning to regression analysis

LECTURE 4: Causal Diagrams - Interaction, Effect Modification, Measurement, Selection Bias

Key Concepts to Focus On:

1. Effect Modification

- **Definition:** When the effect of an exposure on an outcome varies across levels of a third variable
- **Representation:** Not directly shown in standard DAGs, requires additional notation
- **Context dependence:** Whether a variable is an effect modifier depends on other variables in the model

2. Measurement Error Bias Typology

- **Undirected/uncorrelated:** Random error unrelated to true values or other variables
- **Undirected/correlated:** Error related to the true value but not caused by other variables
- **Directed/uncorrelated:** Error influenced by other variables but unrelated to true values
- **Directed/correlated:** Error both influenced by other variables and related to true values

3. Selection Bias and Transportability

- **Selection bias:** when selection into the study is influenced by factors related to exposure and outcome

- **Transportability:** whether findings from a study population apply to a target population
- **Connection:** selection bias can threaten both internal and external validity

Focus Areas for the Test:

- Understand the difference between effect modification and confounding
- Recognise different types of measurement error and their impacts
- Identify selection bias in causal diagrams
- Apply causal diagrams to real research scenarios

LECTURE 5: Causal Inference - Average Treatment Effects

Key Concepts to Focus On:

1. The Fundamental Problem of Causal Inference

- **Definition:** we cannot observe both potential outcomes for the same individual
- **Formal notation:** for individual i, we observe either $Y_i(1)$ or $Y_i(0)$, never both
- **Causal effect:** The contrast between potential outcomes $Y_i(1) - Y_i(0)$

2. Three Fundamental Assumptions for Causal Inference

- **Causal consistency:** $Y_i(a) = Y_i$ when $A_i = a$ (observed outcome equals potential outcome under received treatment)
- **Exchangeability:** Treatment assignment is independent of potential outcomes (possibly conditional on confounders)
- **Positivity:** Non-zero probability of receiving each treatment within each confounder stratum

3. Average Treatment Effect (ATE)

- **Definition:** $E[Y(1) - Y(0)]$ = average difference in potential outcomes across the population
- **Estimation from observed data:** Through g-computation, standardisation, or other methods (to be examined in the second part of course – don't worry about them for now!)
- **Interpretation:** the expected effect if the entire population were treated vs. untreated.

4. Challenges in Observational Studies

- **Consistency challenges:** treatment heterogeneity, interference, definition problems

- **Exchangeability challenges:** unmeasured confounding, selection bias
- **Positivity challenges:** structural zeros, sparse data, practical violations

Focus Areas for the Test:

- Understand potential outcomes framework and counterfactuals
- Know the three fundamental assumptions and their implications
- Recognise how these assumptions allow estimation of average causal effects
- Identify challenges to these assumptions in observational studies

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LECTURE 6: Causal Inference - Understanding How Effects Differ

Key Concepts to Focus On:

1. Interaction vs. Effect Modification

- **Interaction:** the combined effect of two or more interventions (A and B)
- **Effect modification:** How one intervention's effect (A) varies by a baseline characteristic (X)
- **Key distinction:** interaction is about multiple treatments; effect modification is about heterogeneity in a single treatment's effect

2. Causal Interaction

- **Additive interaction:** $E[Y(1,1)] - E[Y(1,0)] - E[Y(0,1)] + E[Y(0,0)]$
- **Interpretation:** Synergy (positive) or antagonism (negative)
- **Confounding control:** Must adjust for confounders of both $A \to Y$ and $B \to Y$ relationships

3. Heterogeneous Treatment Effects (HTE)

- **Concept:** treatment effects vary across individuals or subgroups
- **Importance:** understanding who benefits most from interventions
- **Applications:** targeted treatments, equity considerations, mechanistic insights

4. Conditional Average Treatment Effect (CATE)

- **Definition:** $\tau(x) = E[Y(1) - Y(0)|X = x]$
- **Interpretation:** average effect for subgroup with characteristics X=x
- **Distinction from individual effects:** a group average, not a personal prediction

5. Estimated CATE vs. True Individual Effects

- **Individual causal effect:** $Y_i(1) - Y_i(0)$ (unknowable)
- **Estimated CATE** $\hat{\tau}(X_i)$ our best prediction for people like person i.
- **Limitations:** cannot predict individual-specific effects perfectly

Focus Areas for the Test:

- Distinguish between interaction and effect modification
- Understand how to identify and estimate interaction
- Recognise the concept of effect heterogeneity and its importance
- Understand what CATEs represent and how they differ from individual effects

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MEMORY AIDS

Five Elementary Causal Structures

- Causality Absent: $A \quad B \qquad (A \coprod B)$
- Causality: $A \to B \qquad (A \not\coprod B)$
- Fork: $A \leftarrow C \to B \qquad (A \not\coprod B,\ A \coprod B \mid C)$
- Chain: $A \to C \to B \qquad (A \not\coprod B,\ A \coprod B \mid C)$
- Collider: $A \to C \leftarrow B \qquad (A \coprod B,\ A \not\coprod B \mid C)$

Rules of Confounding Control Summary

1. DO control for common causes (confounders)
2. DO NOT control for mediators (if estimating total effects)
3. DO NOT control for colliders
4. Controlling for descendants has similar effects as controlling for their ancestors

The Fundamental Assumptions Visual

1. Consistency: $Y_i(a) = Y_i$ when $A_i = a$ [What we observe is what would happen under that treatment]

2. Exchangeability: $Y(a) \coprod A|L$ [Treatment assignment is independent of potential outcomes]

3. Positivity: $0 < P(A = a|L = l) < 1$ [Everyone has a chance of each treatment level]

Interaction vs. Effect Modification

1. **Interaction:** How do A and B work together?

2. **Effect Modification**: How does A's effect on Y vary by X?

CROSS-CONNECTIONS BETWEEN LECTURES

1. **Validity** (Lecture 1) relates to **assumptions for causal inference** (Lecture 5):
   - Internal validity requires exchangeability (no unmeasured confounding)
   - External validity relates to transportability (Lecture 4)
2. **Measurement** (Lecture 1) connects to **measurement error bias** (Lecture 4):
   - Measurement challenges can create various forms of bias
   - Cultural differences may lead to different measurement error patterns
3. **Elementary structures** (Lecture 2) are the building blocks for understanding **confounding bias** (Lecture 3):
   - Fork structure creates confounding bias
   - Chain structure relates to mediator bias
   - Collider structure creates selection bias
4. **Effect modification** (Lecture 4) is formalised as **Conditional Average Treatment Effects** (Lecture 6):
   - CATE provides a mathematical way to quantify effect modification
   - Both concepts relate to treatment effect heterogeneity
5. **Average Treatment Effects** (Lecture 5) are affected by the **distribution of effect modifiers** (Lecture 6):
   - Different distributions of effect modifiers can change the ATE even with identical causal mechanisms
   - Important for transportability of findings across populations

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TEST PREPARATION TIPS

1. **Practice drawing causal diagrams** for different research scenarios
2. **Create flashcards** for key terminology and concepts
3. **Explain concepts** to others (e.g. Ziggy) in your own words
4. **Apply the concepts** to your own research interests – e.g. previous observational work or articles you've read.
5. **Review the assumptions** for causal inference and imagine examples in which they might be violated
6. **Consider examples where cultural factors** might impact measurement, effect modification, and transportability

Memorising definitions isn't enough unfortunately. You'll want to understand the conceptual framework of causal inference well enough to be able to reason with it.

Good luck in preparing for your test!