The state of single-case synthesis: Premises, tools, and possibilities

James E. Pustejovsky
pustejovsky@wisc.edu
https://jepusto.com

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John Ferron
Wendy Machalicek
Daniel Swan



Ethan van Norman
David Klingbeil
Man Chen

Positionality

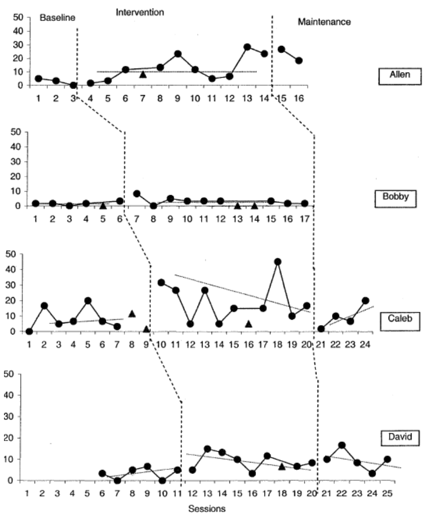
- Trained as statistician.
- Interested in single-case methodology as a toolset for investigating research contexts where other methodologies are infeasible or unsuitable.
- Scholarship focuses on meta-analysis methods, social science applications.
- No experience as interventionist or primary researcher.

Overview

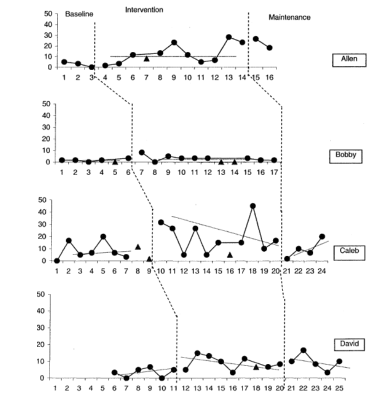
- Premises of synthesis
- Currently available tools for single-case synthesis
- Theoretical possibilities and directions

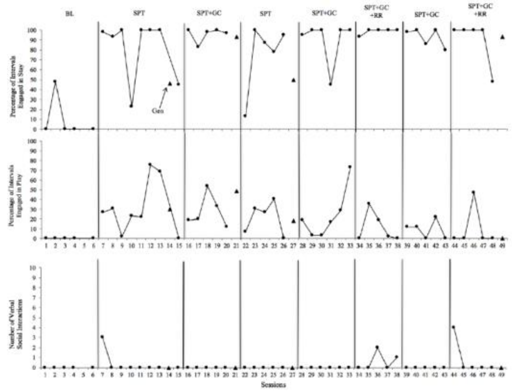
PREMISES

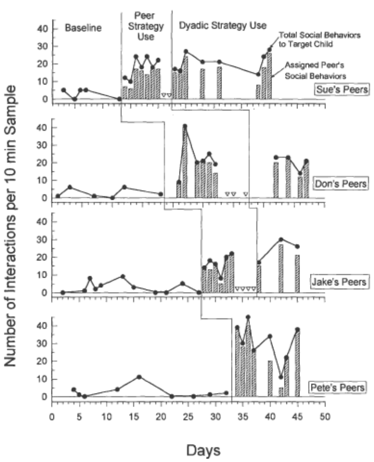
Research synthesis for informing evidenced-based practice

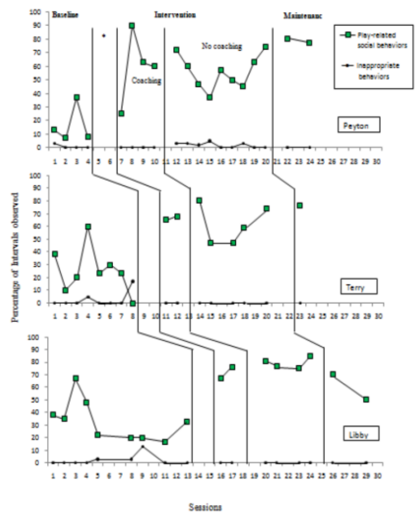


- SCED can provide evidence about intervention effects ***for individual participants***.
- But single SCEDs provided limited basis for ***generalization*** to other participants or contexts.
- Combining evidence from multiple studies can provide a firmer basis for generalization about effects of intervention.



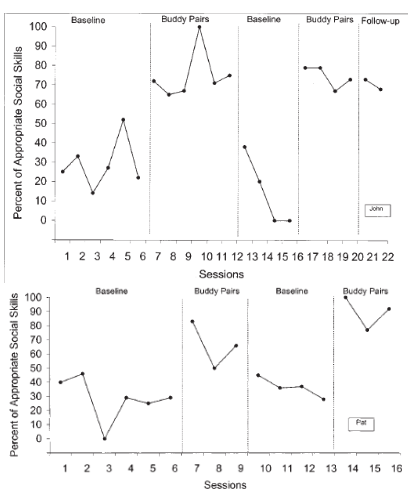


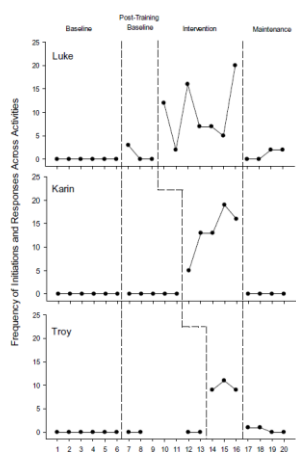


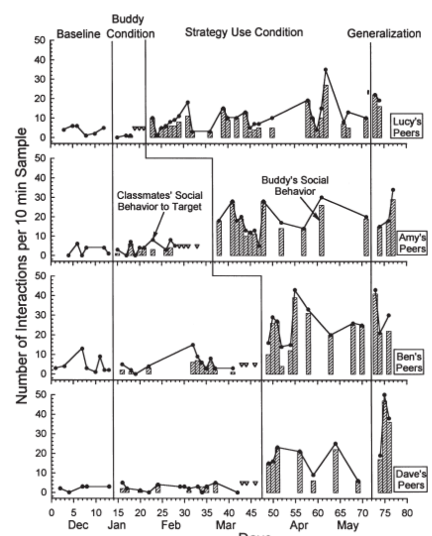


Synthesis of SCEDs

- *Summarize* magnitude of intervention effects.
- Characterize *variation* in effect magnitude.
- Identify *systematic predictors* of effectiveness.







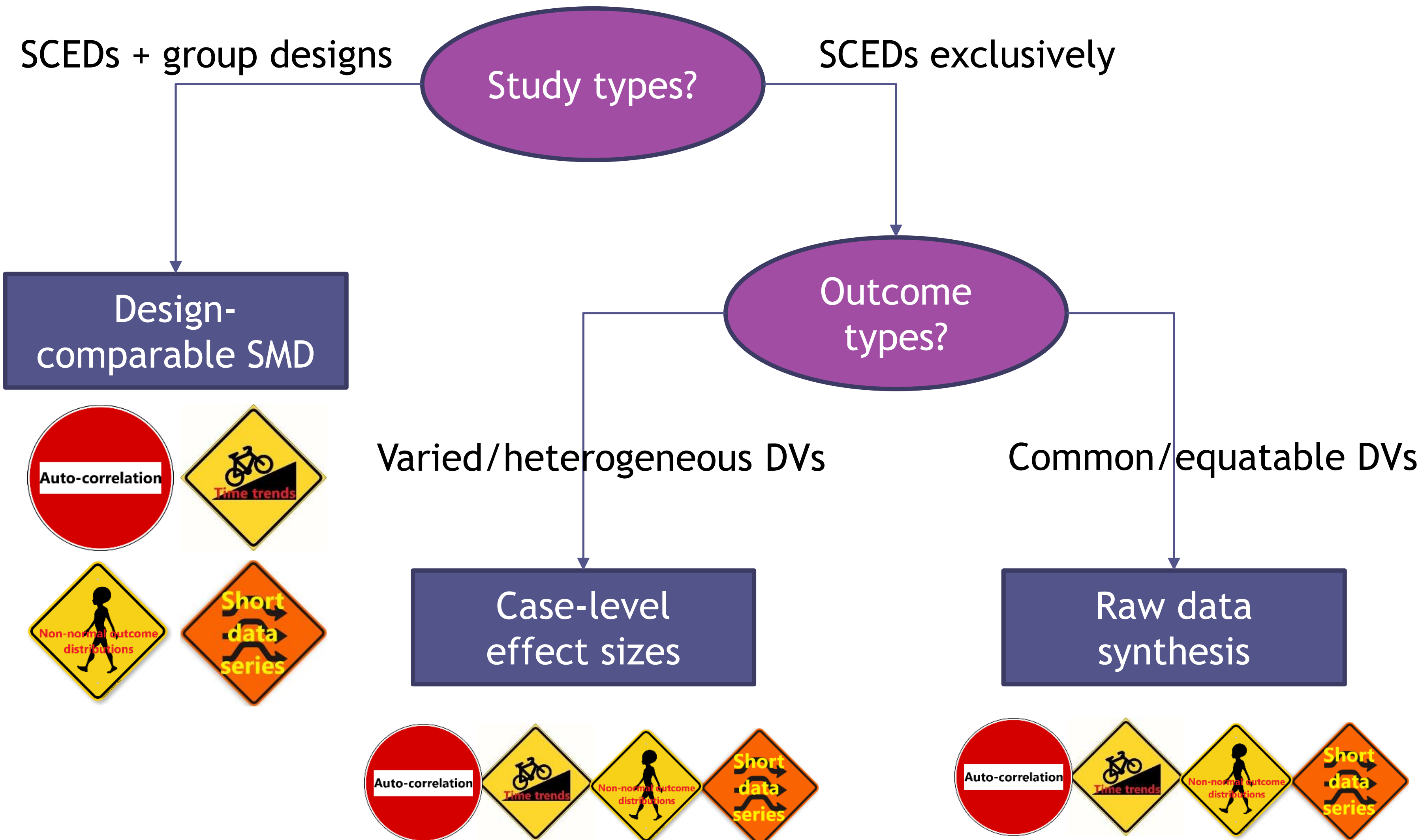
Roadblocks for analysis of SCED data

CURRENT TOOLS

Three broad approaches to synthesis

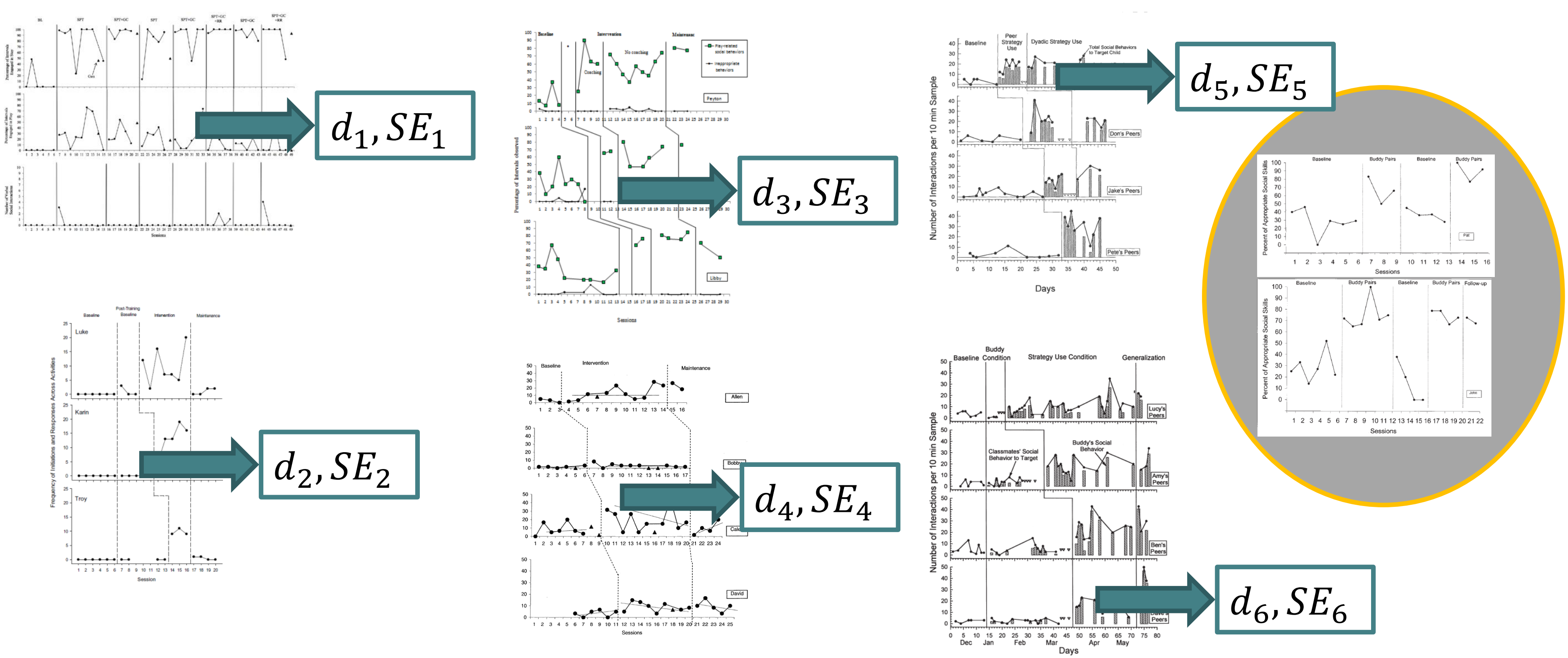
1. Meta-analysis of study-level summary effect sizes (design-comparable standardized mean differences)
2. Meta-analysis of case-level effect sizes
3. Raw data synthesis

Synthesizing single-case research



Study-level summary effect sizes

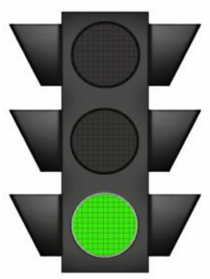
- Between-case standardized mean difference (a.k.a. design-comparable effect size)
- Single-number summary of average intervention effect.



Study-level summary effect sizes

- Goal: Provide a summary effect size in a metric that is theoretically comparable to ES from a between-group design.
  - Can then use conventional meta-analysis methods for synthesis.

- Roadwork completed:
  - ✓ Models account for autocorrelation
  - ✓ Can model time trends



- scdhlm web-app and R package (https://www.jepusto.com/software/scdhlm/)

Study-level summary effect sizes

- Current limitations:
  - Only one available metric (SMD), based on models with normally distributed errors.
  - Requires designs with **3+ participants** in order to estimate between-person variation in outcome (for scale).
  - Limited available designs:
    - Across-participant multiple baseline/multiple probe.
    - Replicated treatment reversals (ABAB).

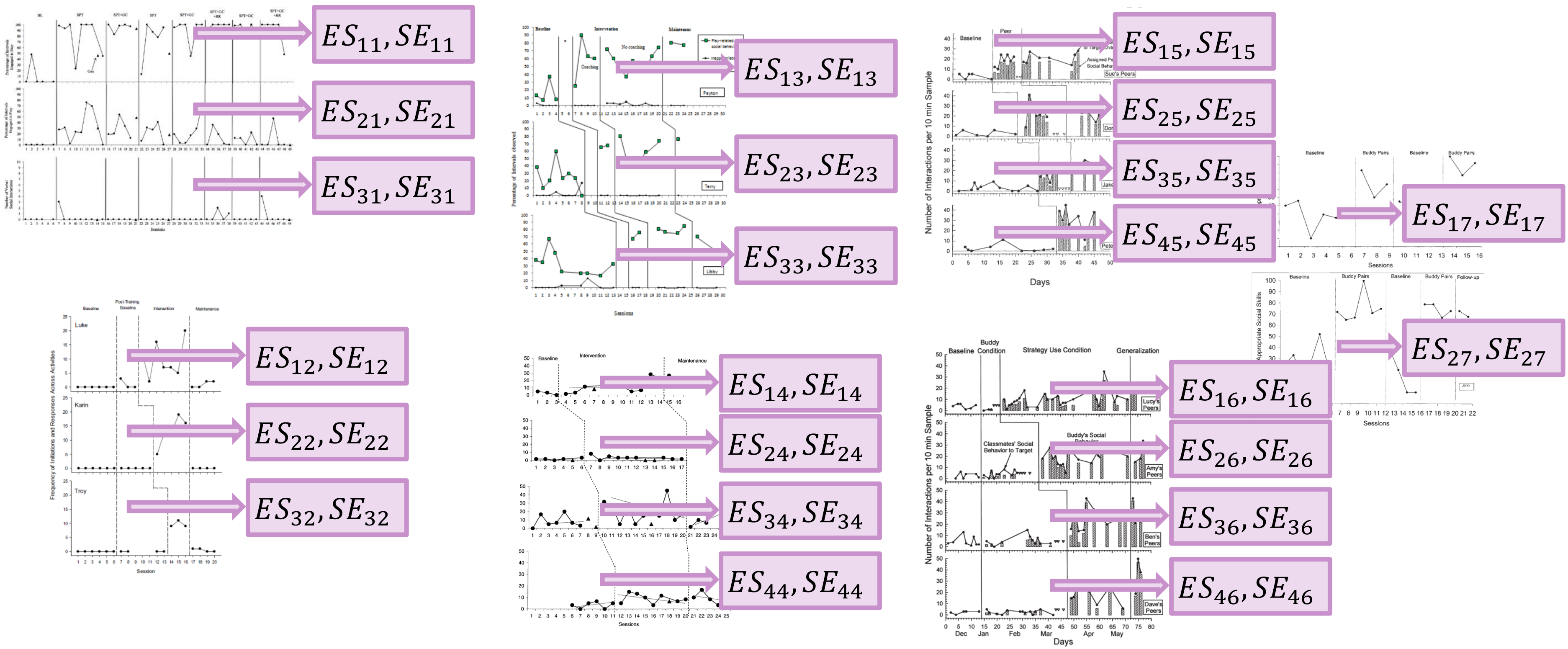
- Chen and colleagues propose extensions for BC-SMD to:
  - Multiple baselines across behaviors, replicated across participants.
  - Clustered multiple baseline designs.
  - Multivariate across-participant multiple baseline designs.

Chen, Pustejovsky, Klingbeil, & Van Norman (2022). Between-case standardized mean differences: Flexible methods for single-case designs. https://psyarxiv.com/3pk5q/

Case-level effect sizes

Case-level effect sizes

- Single-number summary of intervention effect ***for each case***.



Case-level effect sizes

- Goal: Compare results across participants and SCED studies ***that use various outcome measures***.
  - Examine heterogeneity of effects within and between studies.
  - Examine individual-level predictors of effects.

- Many available ES metrics, some appropriate for non-normal outcome distributions.
  - But most available metrics only describe level change.

- SingleCaseES web-app and R package (https://www.jepusto.com/software/SingleCaseES/)

Meta-analysis of case-level effect sizes

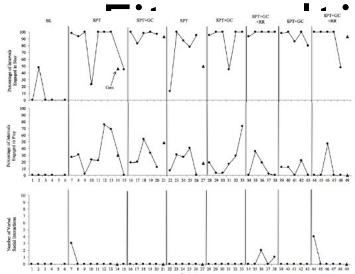
- Because of short data series, strategy for meta-analysis depends on the effect size metric (Chen & Pusto, In Press).

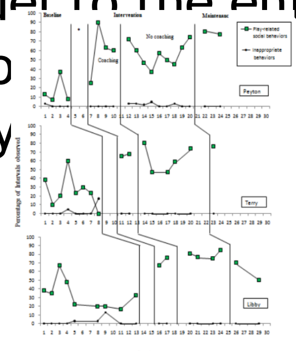
Metric	Strategy	Non-normal outcomes	Auto-correlation	Time trends
Log response ratio	Multi-level meta-analysis			
Within-case SMD	Simple average			
Non-overlap of All Pairs	Simple average			
Tau(AB)	Simple average			

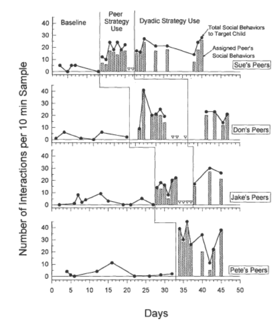
Chen, M., & Pustejovsky, J. E. (In Press). Multi-level meta-analysis of single-case experimental designs using robust variance estimation. Psychological Methods, forthcoming. https://psyarxiv.com/59h32/

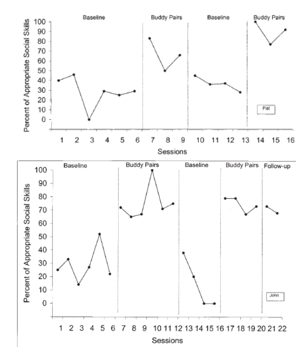
Raw data synthesis

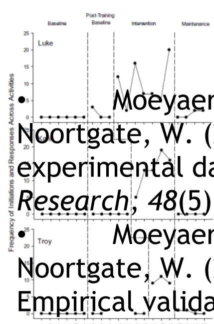
- Combine the raw data from multiple participants & studies.
  - This requires common DVs or DVs that can be meaningfully equated.
- ...-level model to the entire ...an den Noo... 2008; Moey...).

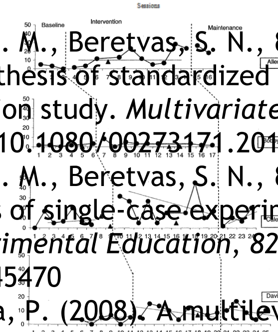


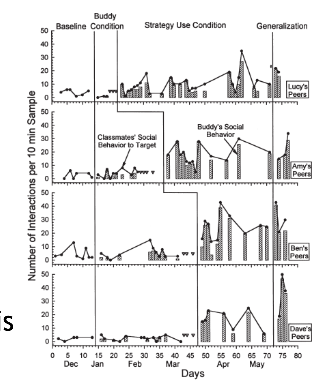










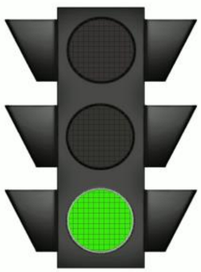


- Moeyaert, M., Ugille, M., Ferron, J. M., Beretvas, S. N., & Van den Noortgate, W. (2013). The three-level synthesis of standardized single-subject experimental data: A monte carlo simulation study. *Multivariate Behavioral Research*, *48*(5), 719–748. http://doi.org/10.1080/00273171.2013.816621
- Moeyaert, M., Ugille, M., Ferron, J. M., Beretvas, S. N., & Van den Noortgate, W. (2014). Three-level analysis of single-case experimental data: Empirical validation. *The Journal of Experimental Education*, *82*(1), 1–21. http://doi.org/10.1080/00220973.2012.745470
- Van den Noortgate, W., & Onghena, P. (2008). A multilevel meta-analysis of single-subject experimental design studies. *Evidence-Based Communication Assessment and Intervention*, 2(3), 142–151. http://doi.org/10.1080/17489530802505362

Raw data synthesis

- Goal: Develop a model that describes the distribution of outcomes (and effects) across studies, cases, & phases.
  - Examine heterogeneity of effects within and between studies.
  - Examine individual-level predictors of effects.
  - Examine temporal variation in effects.

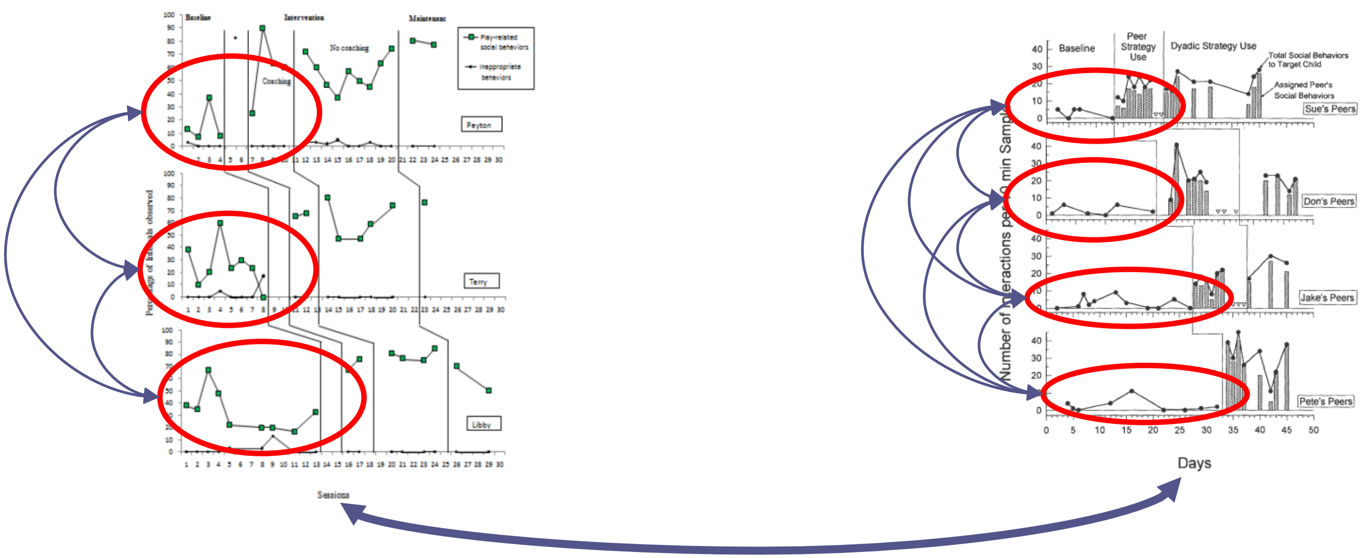
- Roadwork completed:
  - ✓ Models can account for autocorrelation
  - ✓ Can develop models with time trends
  - ✓ Can handle short data series



- MultiSCED web-app (https://ppw.kuleuven.be/single-case)

Raw data synthesis: Assumptions

- Features of baseline data series (levels, slopes, variability) are ***similar across cases and studies***.



- Timing of intervention start/end is ***unrelated to outcome pattern*** (levels, slopes, variability).

Raw data synthesis

- Current limitations:
  - Available methods limited to raw mean difference or within-case SMD metrics.
  - Available models are mostly based on normally distributed errors

- Declercq and colleagues (2020) investigate models for count outcomes.

Declercq, L., Jamshidi, L., Fernández-Castilla, B., Beretvas, S. N., Moeyaert, M., Ferron, J. M., & Van den Noortgate, W. (2019). Analysis of single-case experimental count data using the linear mixed effects model: A simulation study. *Behavior Research Methods*, *51*(6), 2477-2497. https://doi.org/10.3758/s13428-018-1091-y

THEORETICAL POSSIBILITIES AND DIRECTIONS

Three broad approaches to synthesis

	Goal/level of analysis	ES metrics	Assumptions
Study-level summary effect sizes	Study	BC-SMD	Hierarchical model of each study
Case-level effect sizes	Case	Many	Case-specific
Raw data synthesis	Time-point	Raw mean difference, within-case SMD	Hierarchical model across studies

Level of analysis, ES metric, and assumptions are ***theoretically distinct*** and (possibly) ***orthogonal dimensions***.

Theoretical possibilities

Assumptions

ES metric	Study-level analysis	Case-level analysis	Time-point-level analysis
Raw mean difference		X	X
Standardized mean difference (within)		X	X
Standardized mean difference (between)	X		
Response ratio		X	
Odds ratio		X	
Non-overlap		X	
…			

Level of analysis

- Level of analysis should be determined by research aims/research questions.
  - What sources of variation are of interest?
- Higher level of analysis is more reductive, but also simpler to explain.

Effect size metric choice

- ES metric needs to be meaningful and interpretable for the set of interventions and dependent variables identified for synthesis.
- Dependent variable and form of intervention effect should be primary considerations.

Assumptions

- Currently, little recognition of the connection between study procedures and statistical/meta-analytic modeling assumptions.
  - How do response-guided design practices affect assumptions (Joo et al., 2018; Swan et al., 2020)?

- Both substantive SCED researchers and methodologists need to work on ***clarifying and scrutinizing our assumptions***.

- Need better tools for ***investigating model fit***, building confidence in statistical summaries of SCED research.

Joo, S.-H., Ferron, J. M., Beretvas, S. N., Moeyaert, M., & Van den Noortgate, W. (2018). The impact of response-guided baseline phase extensions on treatment effect estimates. Research in Developmental Disabilities, 79, 77–87. https://doi.org/10.1016/j.ridd.2017.12.018
Swan, D. M., Pustejovsky, J. E., & Beretvas, S. N. (2020). The impact of response-guided designs on count outcomes in single-case experimental design baselines. Evidence-Based Communication Assessment and Intervention, 1-26. https://doi.org/10.1080/17489539.2020.1739048

Which combinations are needed?

Assumptions

ES metric	Study-level analysis	Case-level analysis	Time-point-level analysis
Raw mean difference		X	X
Standardized mean difference (within)		X	X
Standardized mean difference (between)	X		
Response ratio		X	
Odds ratio		X	
Non-overlap		X	
…			

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Illustrative use case for BC-SMD

- Calder and colleagues (2020, 2021) studied an explicit grammar instruction intervention for children with developmental language disorder.

- 2020: multiple baseline across nine participants
  - Summary effect sizes after 9 weekly intervention sessions.
  - $d = 1.45, SE = 0.54$ for expressive morphosyntax.
  - $d = -0.04, SE = 0.54$ for grammaticality judgements.

- 2021: crossover randomized trial
  - N = 21 participants
  - $d = 1.97, SE = 0.11$ for expressive morphosyntax.
  - $d = 0.06, SE = 0.06$ for grammaticality judgements.

Calder, S. D., Claessen, M., Ebbels, S., & Leitão, S. (2020). Explicit grammar intervention in young school-aged children with developmental language disorder: An efficacy study using single-case experimental design. Language, Speech, and Hearing Services in Schools, 51(2), 298-316. https://doi.org/10.1044/2019_LSHSS-19-00060
Calder, S. D., Claessen, M., Ebbels, S., & Leitão, S. (2021). The efficacy of an explicit intervention approach to improve past tense marking for early school-age children with developmental language disorder. *Journal of Speech, Language, and Hearing Research*, *64*(1), 91-104. https://doi.org/10.1044/2020_JSLHR-20-00132