Progress in Applied Psychophysiology: Status of the Journal and Results of an Updated Meta-analysis on HRVB

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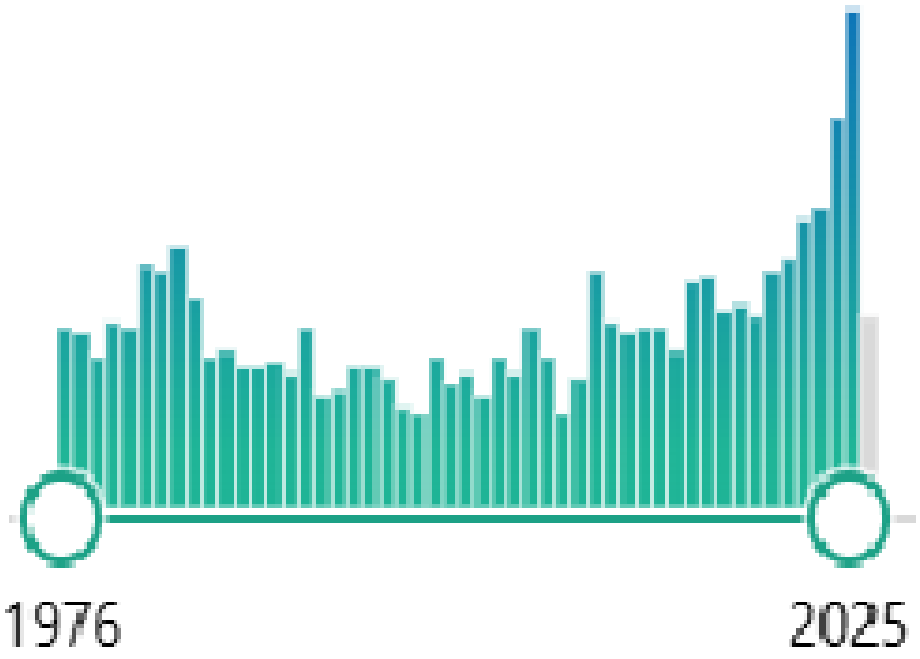
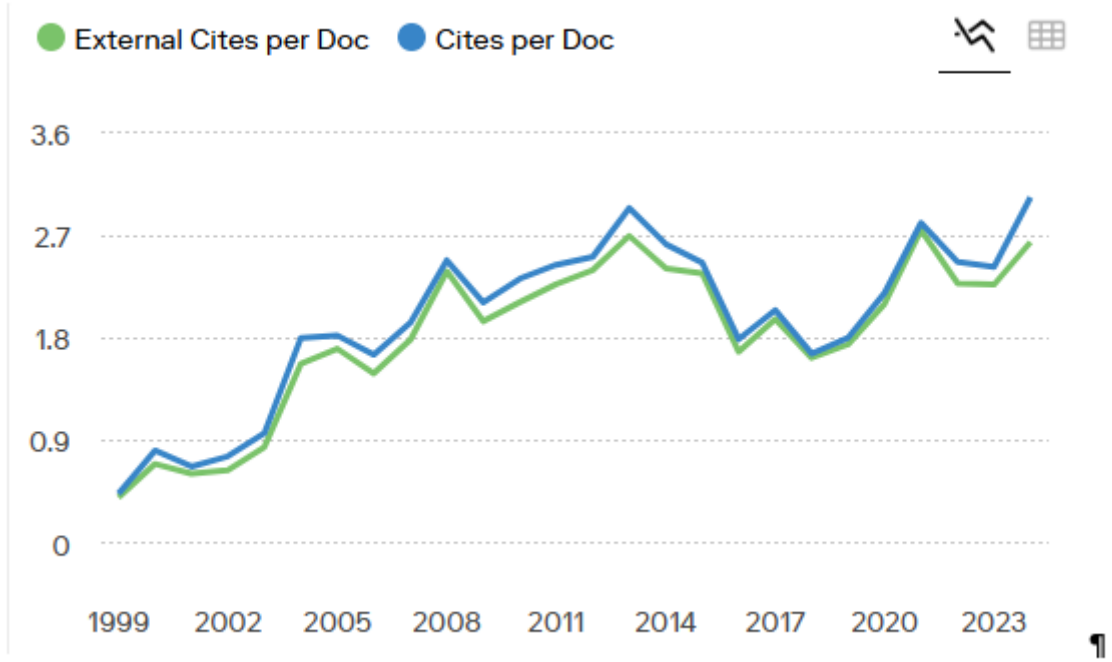
Number of articles in APBI 1976-2025

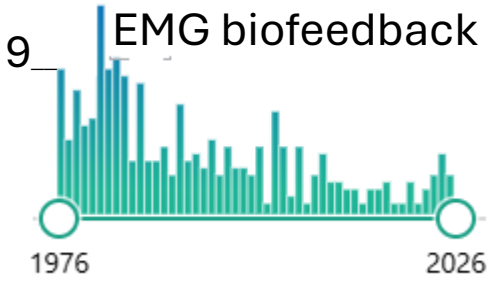


Citations of work in APBI

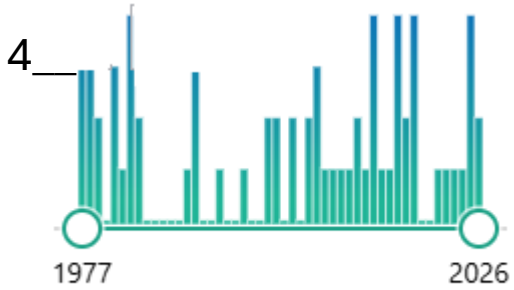


Pubmed searches for APBI content by year (distributions across years)

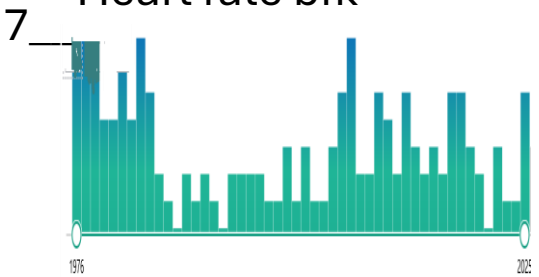
EMG biofeedback



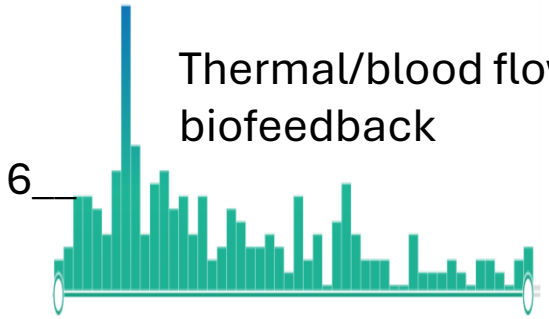
Skin conductance/
Electrodermal biofeedback



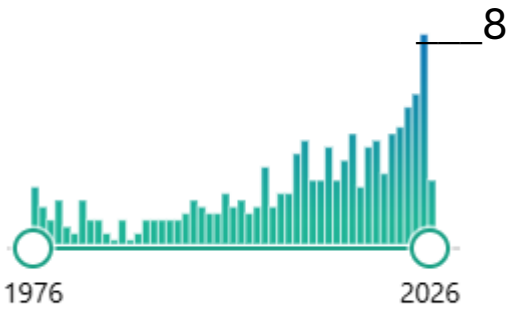
Heart rate bfk



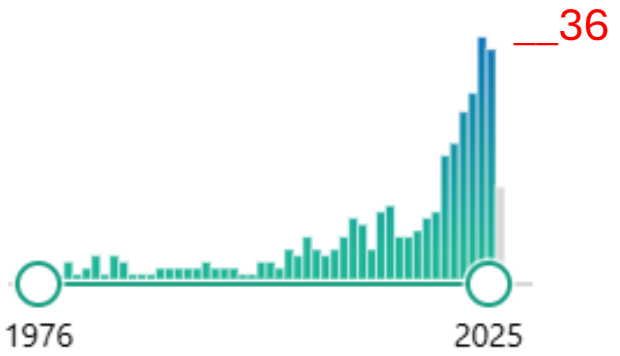
Thermal/blood flow
biofeedback



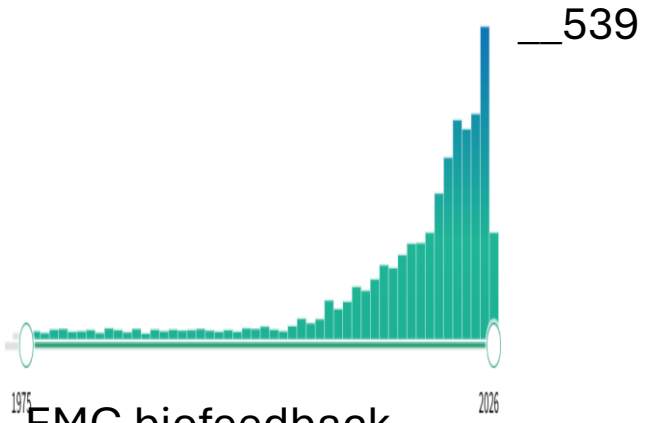
EEG biofeedback
neurofeedback



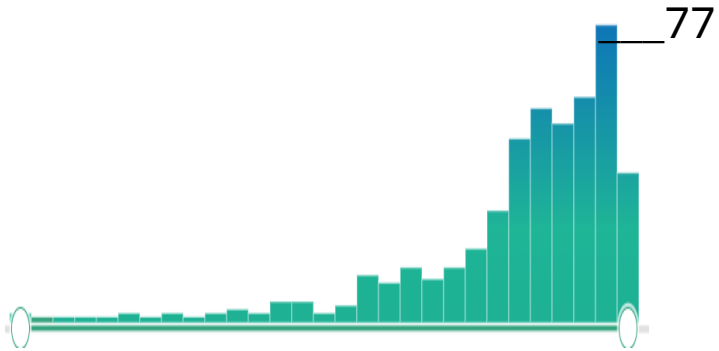
HRV biofeedback



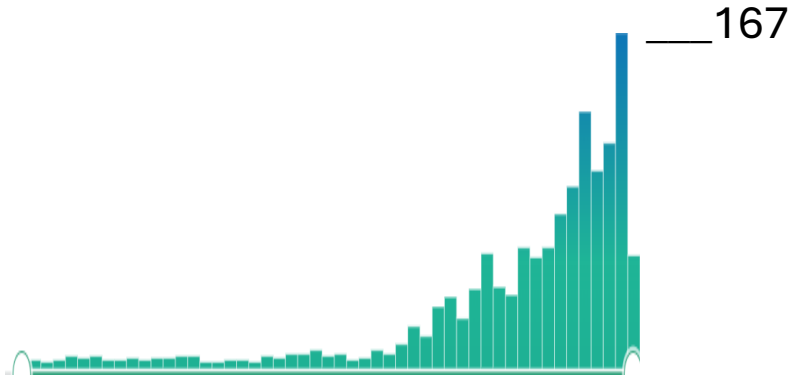
Number of biofeedback papers published in all journals



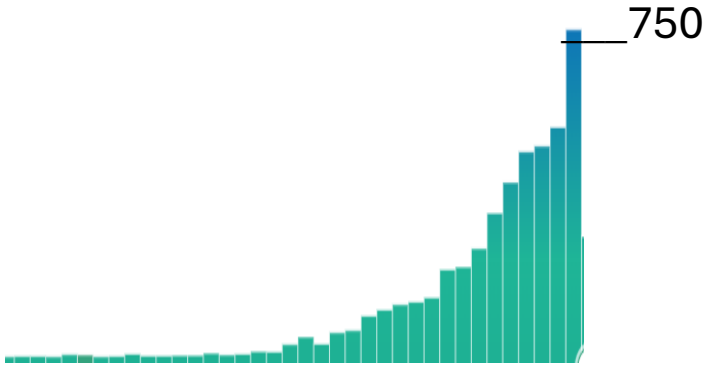
EMG biofeedback



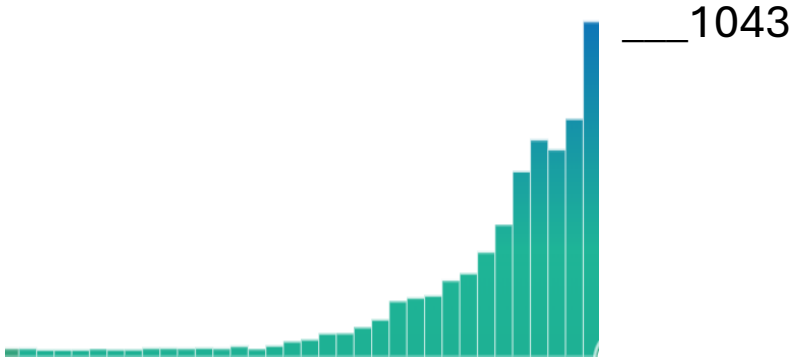
Electrodermal bfk



Thermal bfk

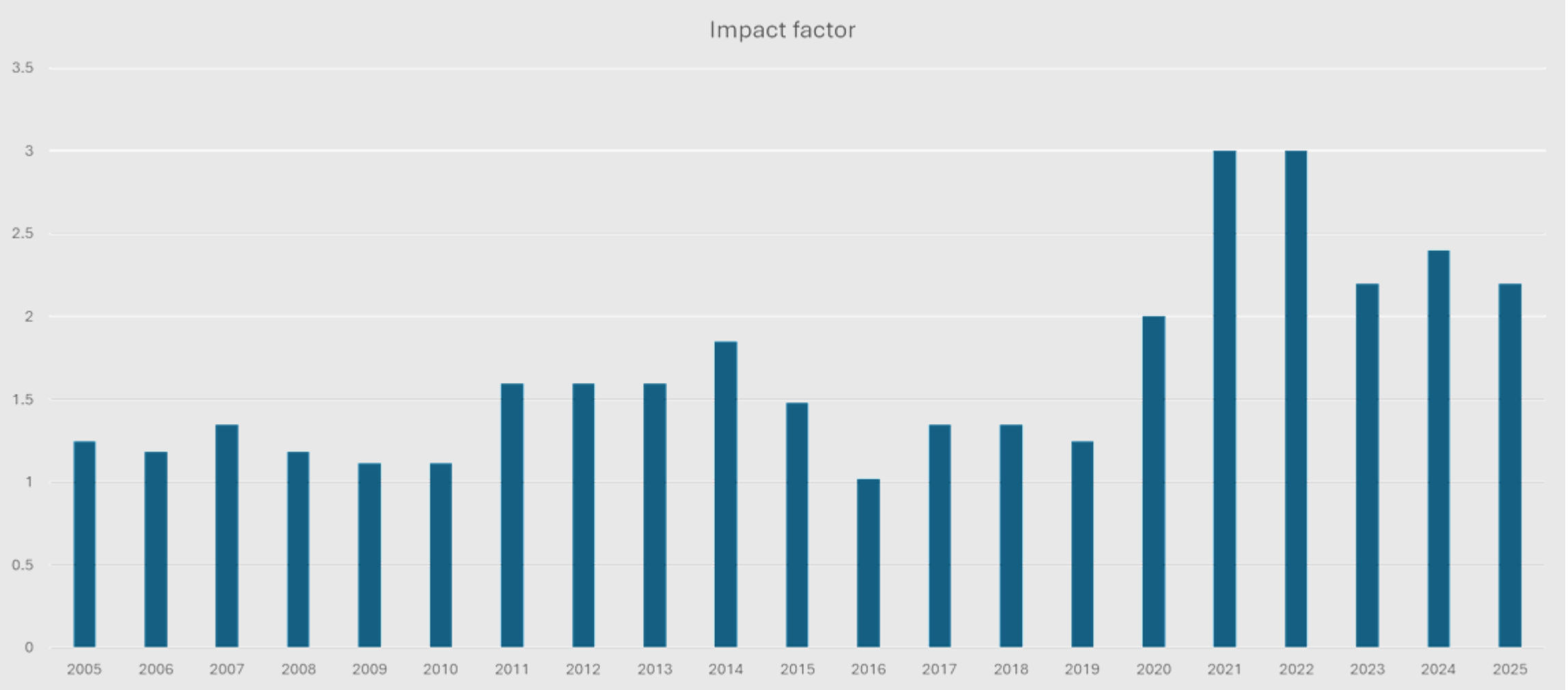


HRV biofeedback



EEG biofeedback

Yearly Impact Factor for APBI



Impact factor compared with other psychophysiology journals (from *Elicit AI*)

Journal	2024 IF	5-yr IF
Psychophysiology	2.8–2.9	3.6–3.8
Biological Psychology	2.8–2.9	2.9
Int. J. of Psychophysiology	2.5–2.6	3.0
Appl. Psychophysiology & Biofeedback	2.4	3.3

Conclusions about APBI

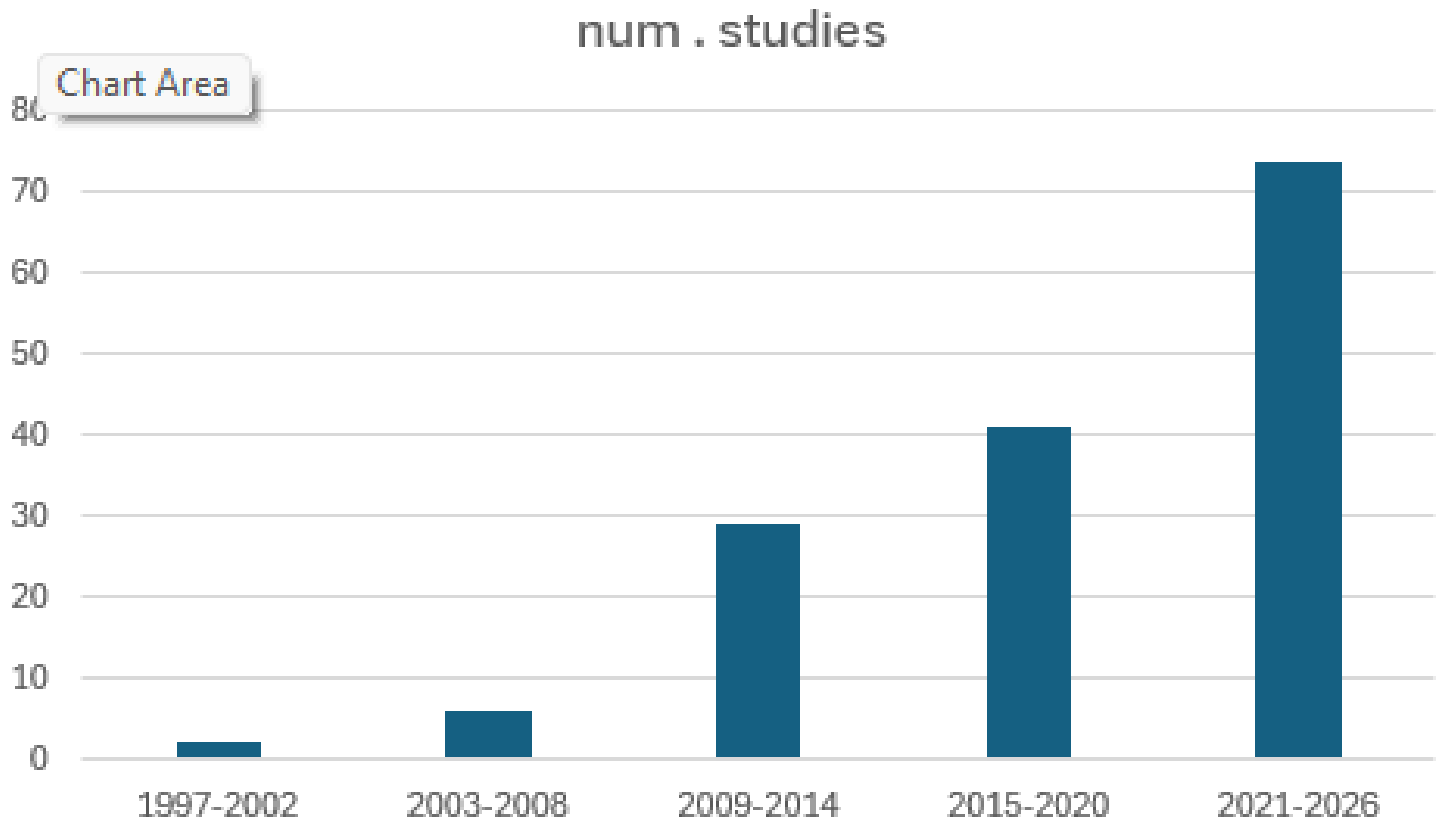
- Doing well in the company of pre-eminent journals in our field
- Is on a trajectory to becoming more prominent
  - Particular improvement in the past 5 years
- The focus is trending toward EEG and HRVB applications in our journal. Other applications also are increasing in interest, but publications go to other journals
- BIOFEEDBACK HAS MADE IT INTO THE MAINSTREAM

Meta-analysis of HRV Biofeedback

The team

- Paul Lehrer, Rutgers Robert Wood Johnson Medical School
- Hannah Brinkman, Rutgers the State University of New Jersey
- Joshua Marchant, Brigham Young University
- David Eddie, Harvard Medical School
- Inna Khazan, Harvard Medical School
- Sigrún Þóra Sveinsdóttir, Reykjavik University
- Karenjot Kaur, NYU Grossman School of Medicine
- Sara Mei, Colorado State University
- Sylvain Laborde, German Sport University
- Teresa Leyro, Rutgers the State University of New Jersey
- Yingting Zhang, Rutgers the State University of New Jersey

Growth in controlled HRVB applications studies



Why a Meta-Analysis

- Need to prove value of HRVB as a component in standard practice
- No funds for a phase III trial
- Many smaller studies are in the literature

Data for Meta Analysis on HRVB and 6/min paced breathing for resilience

- Strategy: conservative
  - All target conditions
  - All measures in all studies (whether or not they are identified as target variables)
  - Controlled study
    - Active as well as inactive controls
  - $n \geq 10$
  - Data compatible with *Comprehensive Meta Analysis* (very flexible)
  - Assume random effects
  - Include nonpublished dissertations / conference papers
  - No exclusions for quality of randomization, concealment

Meta-Analysis Procedure (cont'd)

- Find all studies using HRVB or paced breathing
- For paced breathing, rate must be 0.08-0.11 Hz
- HRVB + another treatment must have other treatment in comparison group too
- Include all outcome measures other than HRV, whether or not they are the focus of the study

- 1590 articles identified from database search and screened by title and abstract
  - PubMed -334
  - CENTRAL -280
  - APA Psycinfo -119
  - CINAHL -340
  - Scopus -118
  - WoS -399
- 328 articles given full-text screening by two people
- 201 studies analyzed
- Total N > 10,000

Caveats about slow paced breathing

Frequency of greatest HRV effects (resonance frequency) differs among people

Most researchers and clinicians do paced breathing at 10 sec (6/min, 0.1 Hz)

Average resonance frequency actually is 11 sec/breath (5.5/min, 0.09 Hz) **not 10 sec**

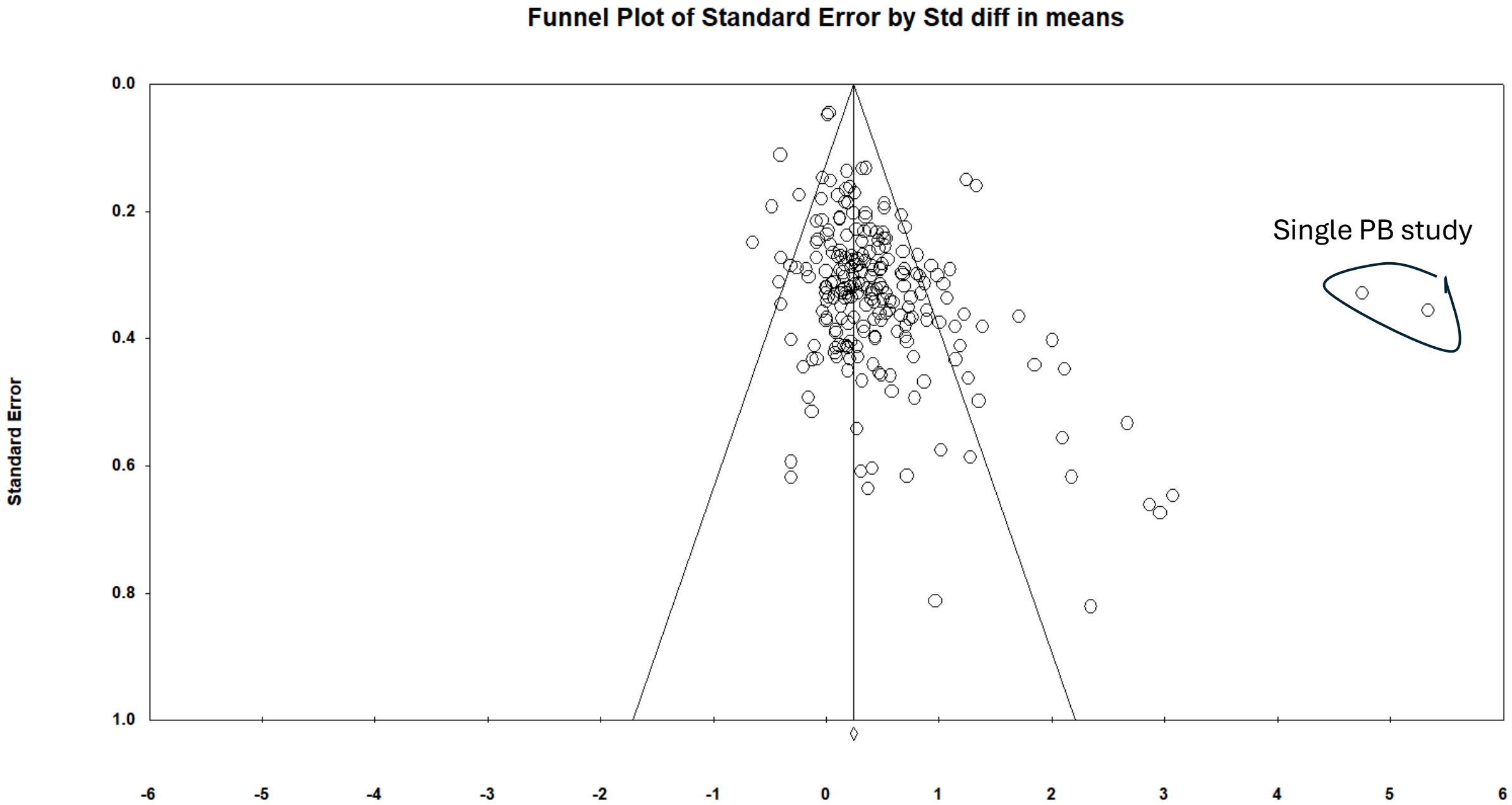
Clinical and HRV effects are slightly bigger at actual resonance frequency

Interpreting Cohen's *d* (effect size, standardized mean difference)
Group differences / pooled standard deviation

• No effect		(< 0.15)
• Small effect	0.2	(0.15 – 0.25)
• Small to medium effect		(0.25 – 0.40)
• Medium effect	0.5	(0.40-0.6)
• Medium to large effect		(0.6 – 0.70)
• Large effect	0.8	(> 0.70)

Considerations in interpreting meta analysis

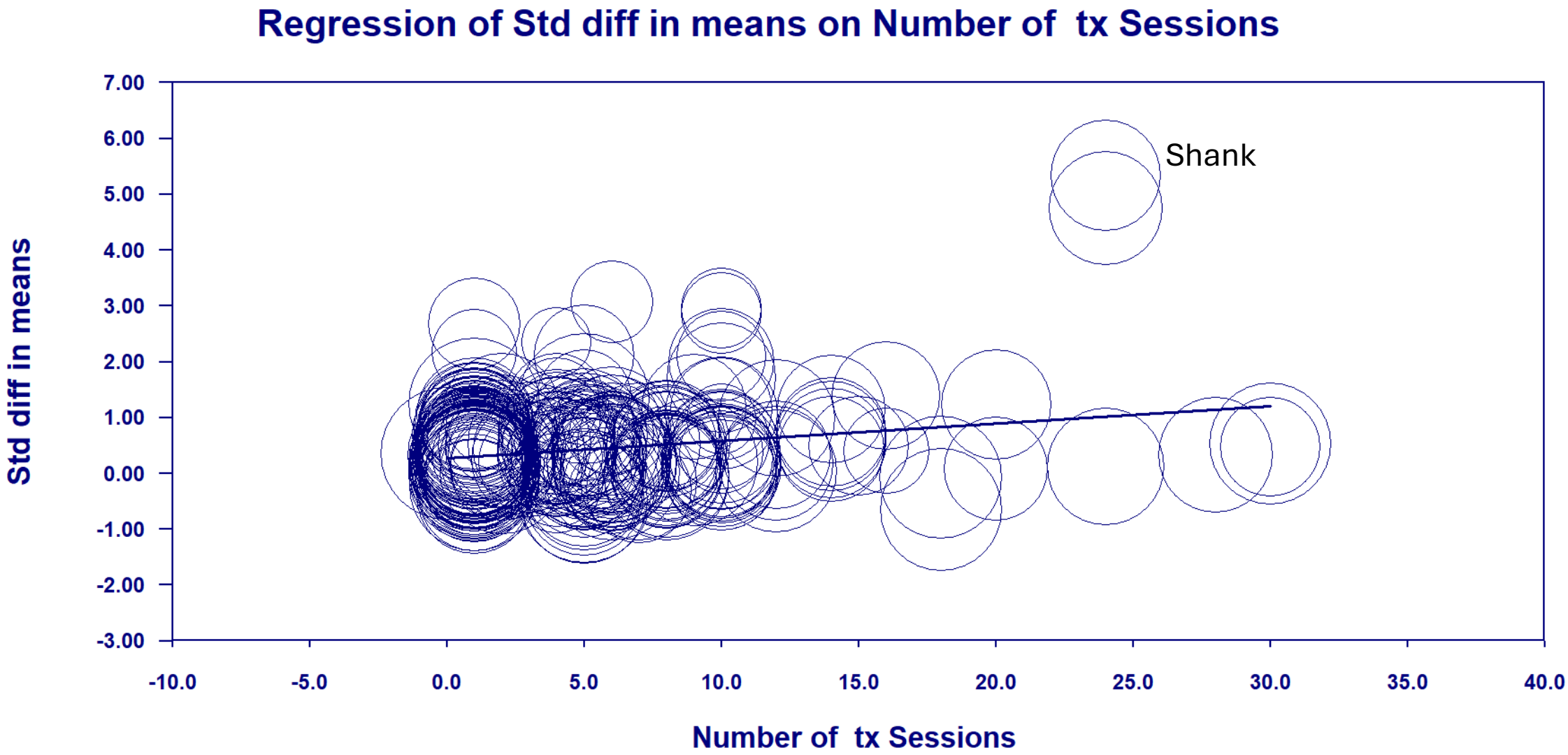
- Heterogeneity and bias (Significant in almost all analyses)
  - Not normally distributed: many positive outliers
- PB vs HRVB
- Active vs. inactive comparisons
- Targeted vs nontargeted measures


Funnel Plot of Standard Error by Std diff in means
Standard Error
0.0
0.2
0.4
0.6
0.8
1.0
-6
-5
-4
-3
-2
-1
0
1
2
3
4
5
6
Single PB study

All studies

Main results for Model 1, Random effects (MM), Z-Distribution, Std diff in means

Covariate	Coefficient	Standard Error	95% Lower	95% Upper	Z-value	2-sided P-value
Intercept	0.2679	0.0571	0.1560	0.3799	4.69	0.0000
Number of tx Sessions	0.0312	0.0073	0.0168	0.0455	4.26	0.0000



Outlier (Shank, et al, 2023)

- paced breathing study
- anxiety among 144 Palestinian children living in circumstances of armed conflict
- $d > 5.0$
- Large number of sessions (25)
- Better than average methods for statistical baseline control and blinding of assessors and data analyzers
- Probably not biased, but omitted because an outlier

Analyses with all studies

- Number of participants > 15,000

- All studies, PB and HRVB: medium effect size
  - With outlier: $d = 0.420$, $k = 227$, $p < 0.0005$ (medium)
  - Without outlier: $d = 0.392$, $k = 226$, $p < 0.0005$ (small to medium)

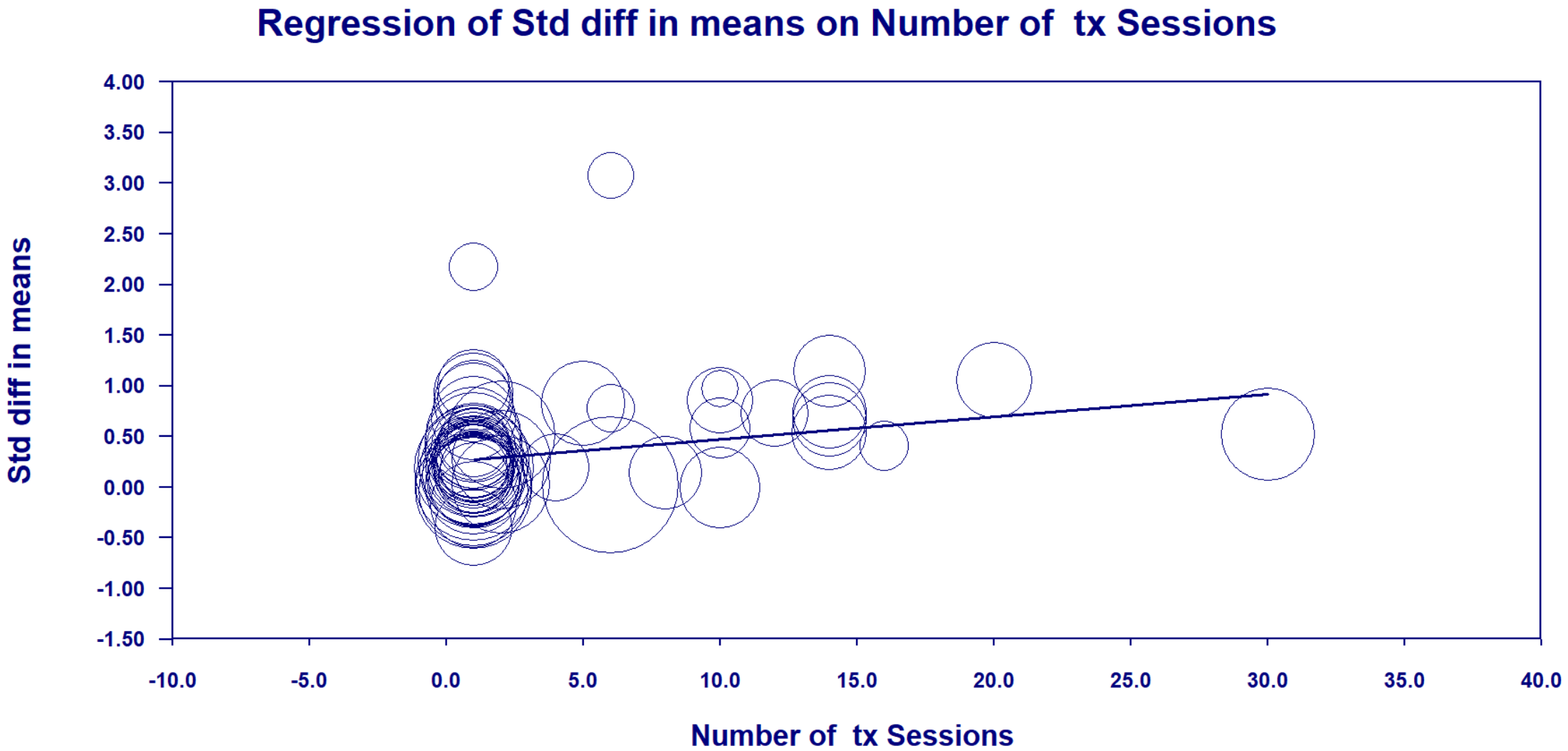
Analyses without outlier (and all subsequent analyses)

- Compared with other active treatments: small significant effect size
  - $d = 0.163$, $k = 56$, $p = 0.011$
- Compared with inactive conditions: medium effect size
  - $d = 0.468$, $k = 170$, $p < 0.0005$
- Targeted vs nontargeted measures
  - Targeted: $d = 0.561$, $k = 107$, $p < 0.0005$ (medium)
  - Nontargeted: $d = 0.388$, $k = 107$, $p < 0.0005$ (small to medium)
- HRVB vs PB (inactive targeted comparisons)
  - HRVB: $d = 0.471$, $k = 121$, $p < 0.0005$ (medium)
  - PB: $d = 0.264$, $k = 16$, $p = 0.046$ (small to medium)
  - Not significantly different, $Q(1) = 0.246$, $p = 0.143$

Paced breathing studies without outlier

Main results for Model 1, Random effects (MM), Z-Distribution, Std diff in means

Covariate	Coefficient	Standard Error	95% Lower	95% Upper	Z-value	2-sided P-value
Intercept	0.2484	0.0578	0.1351	0.3616	4.30	0.0000
Number of tx Sessions	0.0222	0.0086	0.0053	0.0391	2.57	0.0102

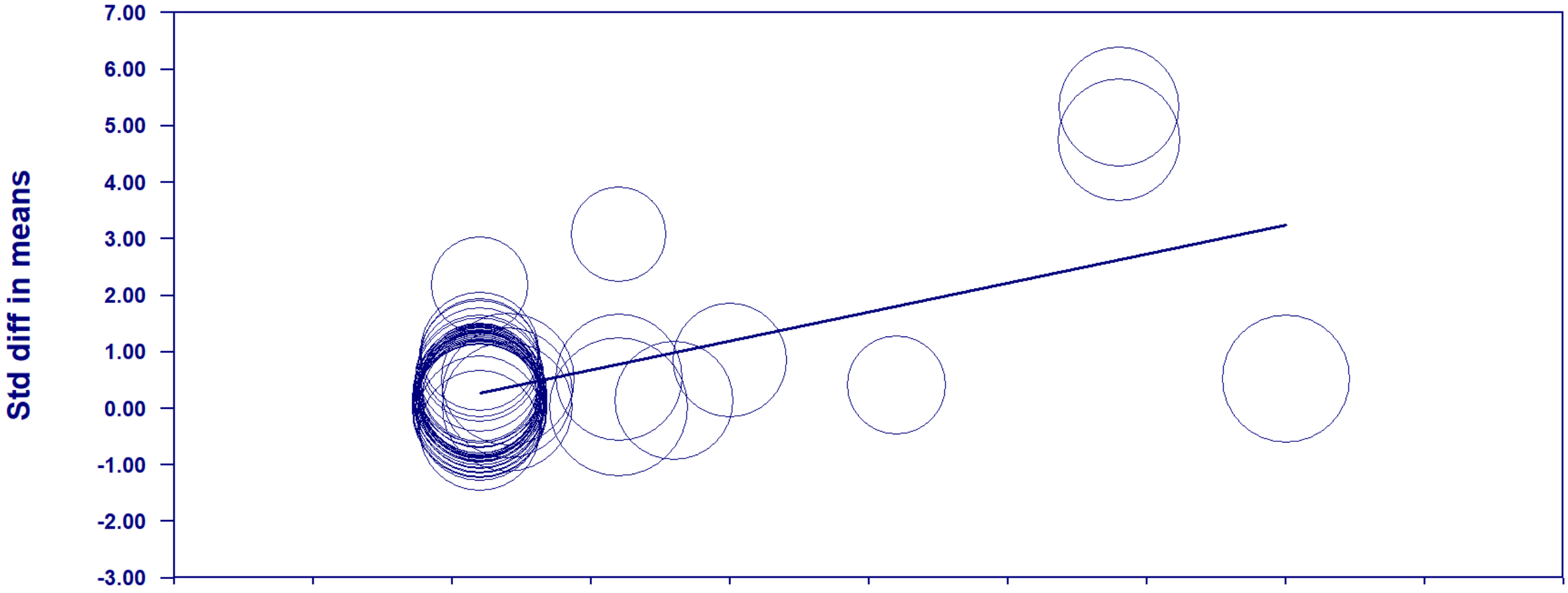


Number of sessions HRVB studies

Main results for Model 1, Random effects (MM), Z-Distribution, Std diff in means

Covariate	Coefficient	Standard Error	95% Lower	95% Upper	Z-value	2-sided P-value
Intercept	0.1725	0.1126	-0.0482	0.3932	1.53	0.1255
Number of tx Sessions	0.1024	0.0154	0.0723	0.1326	6.65	0.0000

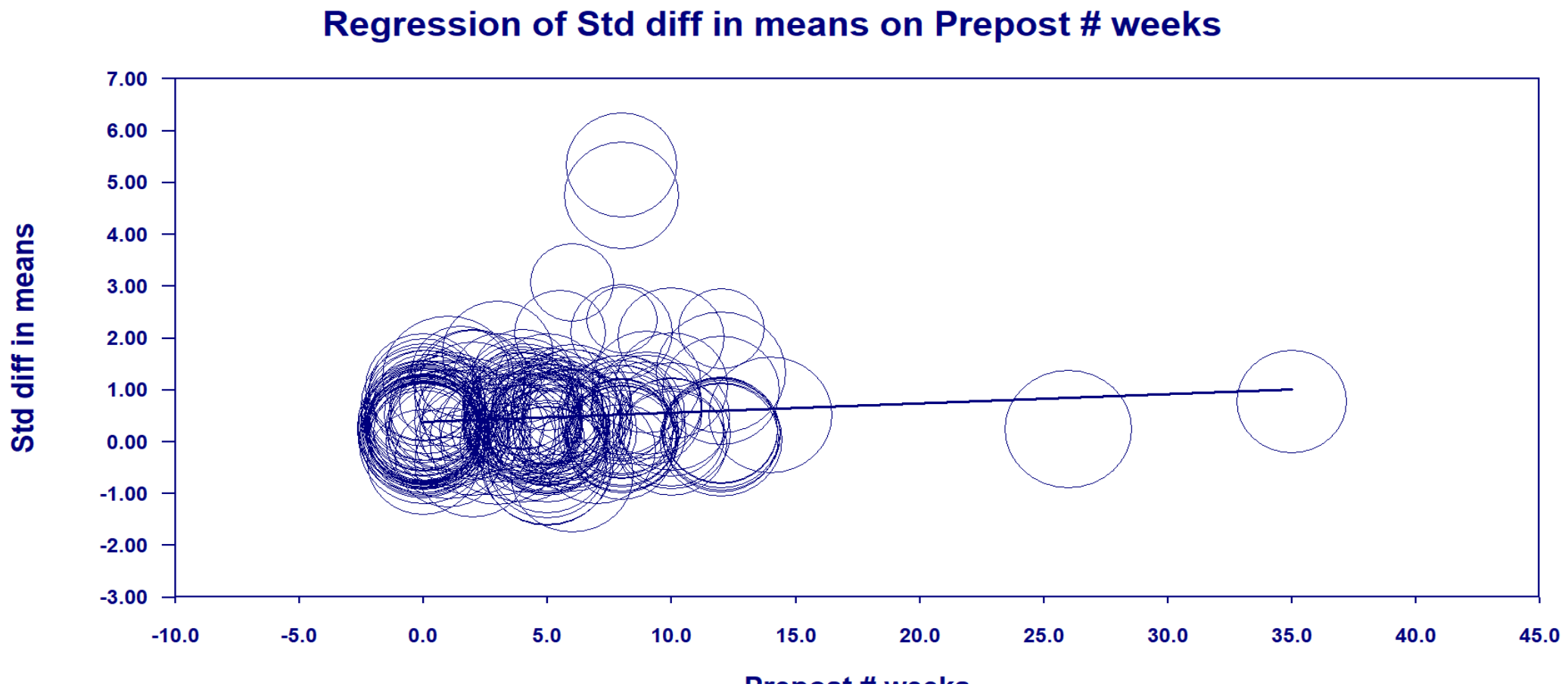
Regression of Std diff in means on Number of tx Sessions



Main results for Model 1, Random effects (MM), Z-Distribution, Std diff

ALL STUDIES

Covariate	Coefficient	Standard Error	95% Lower	95% Upper	Z-value	2-sided P-value
Intercept	0.3779	0.0664	0.2477	0.5081	5.69	0.0000
Prepost # weeks	0.0180	0.0101	-0.0018	0.0377	1.78	0.0743



Effect sizes by bias ratings

Bias rating	*k*	*d*
Blank	19	0.328
high	3	1.119
low	7	0.799
medium	29	0.417

SUMMARY OF META ANALYSIS FINDINGS (inactive comparisons)

LARGE EFFECT SIZE

	d	***k***
Respiratory px	1.22	5
Nonclin pain	1.11	3
Athletic perform (targ.)	1.06	7
Clin. Anxiety	1.04	16

MEDIUM – LARGE EFFECT SIZE

	d	***k***
Systolic BP (HRVB only)	0.67	13
Clin. Sleep	0.62	7

SUMMARY OF META ANALYSIS FINDINGS (inactive comparisons)

MEDIUM

	d	*k*
Craving (targ.)	0.56	9
Cognitive function (active comparisons)	0.51	9
Heart rate	0.51	6
Depression targ.	0.47	28
Anger	0.45	7
Inflammation/amyloids	0.43	7
Clin. Pain	0.41	7
PTSD	0.40	7
Clin. Depression	0.38	23

SMALL TO MEDIUM

	d	*k*
Stress nontarg	0.33	23
Diastolic BP (targ)	0.32	7

SMALL

Cortisol	0.24	5

Other conditions with significant effects in single studies

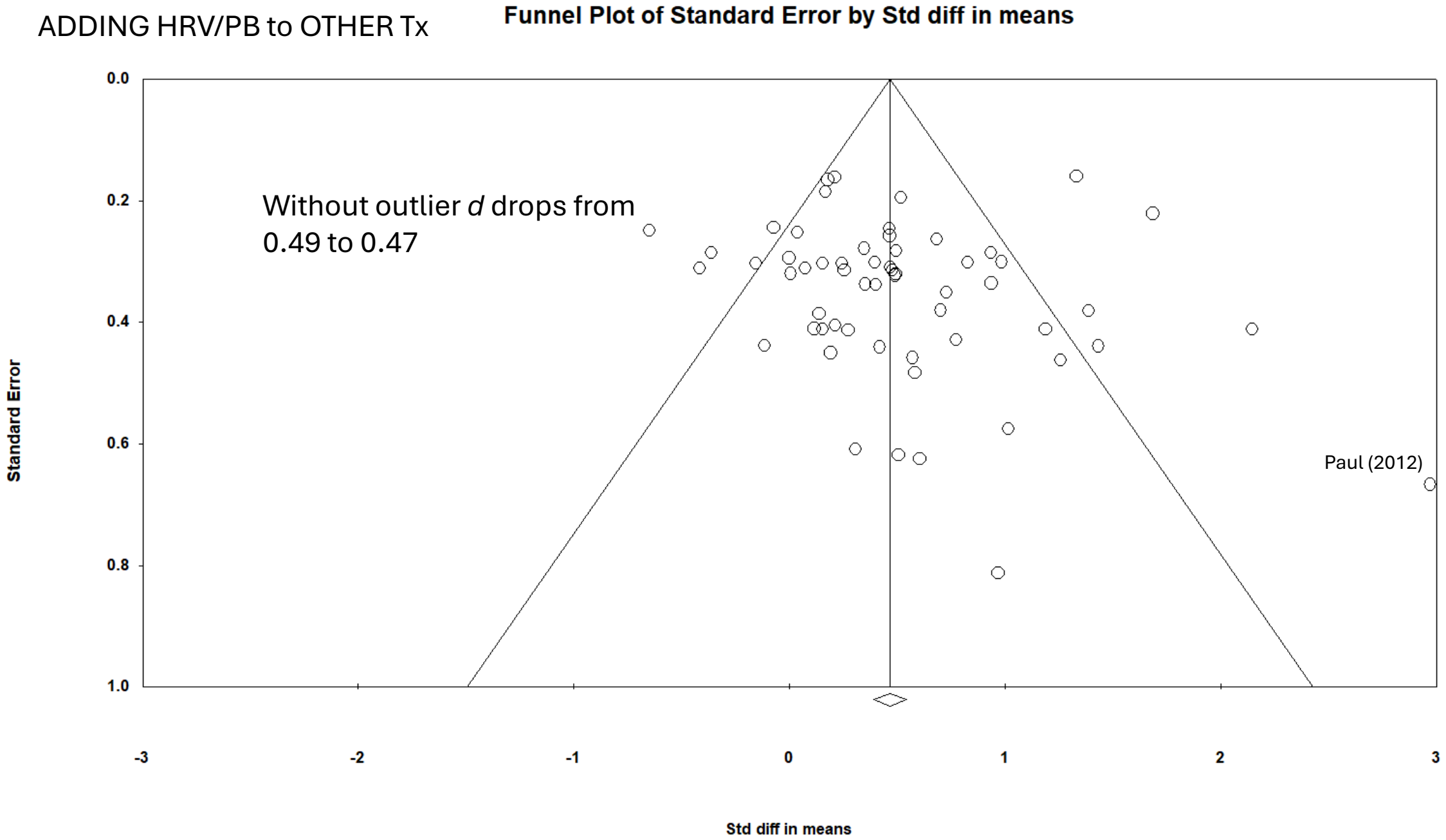
- Female sexual arousal
- Neuroplastic prefrontal increases
- Limbic-prefrontal connectivity (2 studies)
- Brain increased activity in motor and visuospatial areas
- Somatization symptoms
- Executive function
- G-I disorders

Adding HRVB/PB to another treatment: Moderate effect size

Effect size and 95% confidence interval						Test of null (2-Tail)		Prediction Interval	
Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit
59	0.491	0.075	0.006	0.344	0.639	6.525	0.000	-0.443	1.425

Between-study		Other heterogeneity statistics			
Tau	TauSq	Q-value	df (Q)	P-value	I-squared
0.460	0.212	190.369	58	0.000	69.533

ADDING HRV/PB to OTHER Tx



caveats

- Heterogeneity and positive skewness. Possibly inflated *d*
- 0.1 Hz paced breathing may have underestimated results
- Small k for some applications
- Effect size is not the same as clinical significance: need clinical significance evaluation

conclusions

- Meta analysis is the closest we get to Phase III trials: use it
- Generally moderate effect size, slightly stronger for HRVB than 6/min breathing
- More training helps
- Particularly promising applications (large or medium to large effect sizes)
  - Respiratory disorders
  - Acute (not chronic or clinical) pain
  - Athletic performance
  - Anxiety
  - Systolic blood pressure
  - Sleep

conclusions

Possibly important areas of application (medium effect size)

- Craving
- Cognitive function
- Depression
- Anger
- Inflammation
- Alzheimer ‘s prevention and treatment (amyloids)
- Pain
- PTSD

Surprising small effect size

- Cortisol

- Possible explanation
  - Primary stress response is inflammation
  - Indirect relationship to stress
    - Cortisol is anti-inflammatory; may represent a homeostatic response

- Stress in stressed individuals

Model		Effect size and 95% confidence interval					Test of null (2-Tail)	
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value
Fixed	227	0.246	0.016	0.000	0.215	0.276	15.773	0.000
Random	227	0.429	0.037	0.001	0.356	0.502	11.580	0.000

Prediction Interval		Between-study		Other heterogeneity statistics			
Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
				1030.803	226	0.000	78.075
-0.463	1.321	0.451	0.204				

anxiety

Paed breathing except outlier

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statis		
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value
Fixed	53	0.210	0.036	0.001	0.140	0.280	5.899	0.000					319.463	52	0.0
Random	53	0.381	0.094	0.009	0.198	0.565	4.075	0.000	-0.829	1.592	0.596	0.355			

Paced Breathing studies: Active vs. Inactive Controls

Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
	23	0.161	0.065	0.004	0.033	0.288	2.466	0.014					45.622	22	0.002	51.778
active	43	0.084	0.023	0.001	0.038	0.130	3.591	0.000					79.911	42	0.000	47.442
inactive	146	0.371	0.023	0.001	0.326	0.415	16.339	0.000					592.637	145	0.000	75.533
Total within													718.170	209	0.000	
Total between													78.545	2	0.000	
Overall	212	0.228	0.016	0.000	0.197	0.259	14.401	0.000					796.715	211	0.000	73.516
Mixed effects analysis																
	23	0.243	0.106	0.011	0.035	0.451	2.289	0.022	-0.525	1.011	0.375	0.141				
active	43	0.258	0.073	0.005	0.115	0.401	3.534	0.000	-0.495	1.011	0.375	0.141				
inactive	146	0.454	0.041	0.002	0.374	0.534	11.115	0.000	-0.290	1.197	0.375	0.141				
Total between													7.626	2	0.022	
Overall	212	0.390	0.034	0.001	0.324	0.457	11.561	0.000	-0.383	1.164	0.391	0.153				

Paced breathing vs. HRVB without outlier

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
HRVB	192	0.352	0.021	0.000	0.310	0.393	16.534	0.000					520.425	191	0.000	63.299
PB	50	0.096	0.022	0.000	0.052	0.139	4.316	0.000					103.549	49	0.000	52.680
Total within													623.975	240	0.000	
Total between													69.566	1	0.000	
Overall	242	0.229	0.015	0.000	0.199	0.259	14.914	0.000					693.541	241	0.000	65.251
Mixed effects analysis																
HRVB	192	0.398	0.033	0.001	0.334	0.462	12.130	0.000	-0.222	1.017	0.313	0.098				
PB	50	0.281	0.059	0.004	0.165	0.398	4.729	0.000	-0.346	0.908	0.313	0.098				
Total between													2.968	1	0.085	
Overall	242	0.371	0.029	0.001	0.314	0.427	12.905	0.000	-0.287	1.028	0.332	0.111				

HRVB and PB both significant, HRVB nonsignificantly stronger $p < .09$

$d =$ .398 and .201

Active v Inactive Controls, PB AND HRVB COMBINED without outlier

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
active	61	0.073	0.022	0.000	0.030	0.117	3.305	0.001					92.015	60	0.005	34.793
inactive	181	0.371	0.021	0.000	0.329	0.412	17.474	0.000					507.675	180	0.000	64.544
Total within													599.690	240	0.000	
Total between													93.851	1	0.000	
Overall	242	0.229	0.015	0.000	0.199	0.259	14.914	0.000					693.541	241	0.000	65.251
Mixed effects analysis																
active	61	0.186	0.055	0.003	0.079	0.293	3.404	0.001	-0.420	0.792	0.303	0.092				
inactive	181	0.436	0.033	0.001	0.371	0.501	13.216	0.000	-0.164	1.036	0.303	0.092				
Total between													15.416	1	0.000	
Overall	242	0.369	0.028	0.001	0.314	0.424	13.070	0.000	-0.288	1.026	0.332	0.111				

Significant for inactive controls, not for active controls. Difference is significant

Targeted vs untargeted measures

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
no	165	0.168	0.017	0.000	0.134	0.202	9.671	0.000					379.969	164	0.000	56.839
yes	138	0.294	0.021	0.000	0.252	0.336	13.754	0.000					476.170	137	0.000	71.229
Total within													856.139	301	0.000	
Total between													20.795	1	0.000	
Overall	303	0.218	0.013	0.000	0.192	0.245	16.184	0.000					876.935	302	0.000	65.562
Mixed effects analysis																
no	165	0.313	0.036	0.001	0.243	0.382	8.774	0.000	-0.340	0.965	0.330	0.109				
yes	138	0.428	0.040	0.002	0.350	0.506	10.709	0.000	-0.226	1.082	0.330	0.109				
Total between													4.632	1	0.031	
Overall	303	0.364	0.027	0.001	0.312	0.416	13.676	0.000	-0.287	1.014	0.329	0.109				

Targeted significantly stronger, both significant

HRVB only Anxiety targeted vs nontargeted

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
no	33	0.173	0.056	0.003	0.064	0.283	3.099	0.002					34.001	32	0.371	5.886
yes	23	0.510	0.065	0.004	0.383	0.637	7.882	0.000					142.011	22	0.000	84.508
Total within													176.013	54	0.000	
Total between													15.484	1	0.000	
Overall	56	0.317	0.042	0.002	0.235	0.400	7.500	0.000					191.496	55	0.000	71.279
Mixed effects analysis																
no	33	0.153	0.104	0.011	-0.051	0.357	1.469	0.142	-0.836	1.141	0.482	0.232				
yes	23	0.559	0.129	0.017	0.306	0.812	4.333	0.000	-0.441	1.560	0.482	0.232				
Total between													6.015	1	0.014	
Overall	56	0.313	0.081	0.007	0.154	0.471	3.862	0.000	-0.706	1.332	0.502	0.252				

Targeted k = 20 Nontargeted k = 32

Moderate significant effect size for targeted
Nonsignificant effect for nontargeted

Targeted vs nontargeted anxiety

High resolution plot

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
no	37	0.182	0.053	0.003	0.079	0.286	3.461	0.001					44.801	36	0.149	19.645
yes	24	0.499	0.064	0.004	0.374	0.624	7.829	0.000					142.990	23	0.000	83.915
Total within													187.791	59	0.000	
Total between													14.646	1	0.000	
Overall	61	0.311	0.041	0.002	0.231	0.391	7.657	0.000					202.437	60	0.000	70.361
Mixed effects analysis																
no	37	0.183	0.097	0.009	-0.007	0.374	1.887	0.059	-0.785	1.151	0.474	0.225				
yes	24	0.539	0.125	0.016	0.295	0.784	4.320	0.000	-0.441	1.520	0.474	0.225				
Total between													5.059	1	0.024	
Overall	61	0.318	0.077	0.006	0.167	0.468	4.143	0.000	-0.677	1.313	0.491	0.241				

Targeted k = 21 Nontargeted k = 35

HRVB + PB Depression targeted & nontargeted

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
no	30	0.275	0.054	0.003	0.169	0.381	5.078	0.000					64.838	29	0.000	55.273
yes	35	0.397	0.055	0.003	0.288	0.505	7.173	0.000					61.120	34	0.003	44.372
Total within													125.958	63	0.000	
Total between													2.481	1	0.115	
Overall	65	0.335	0.039	0.001	0.259	0.410	8.646	0.000					128.440	64	0.000	50.171
Mixed effects analysis																
no	30	0.259	0.082	0.007	0.098	0.420	3.158	0.002	-0.388	0.907	0.313	0.098				
yes	35	0.389	0.079	0.006	0.235	0.543	4.949	0.000	-0.257	1.035	0.313	0.098				
Total between													1.308	1	0.253	
Overall	65	0.327	0.057	0.003	0.216	0.438	5.759	0.000	-0.310	0.965	0.314	0.099				

Targeted k = 30 Nontargeted k = 27

Sleep PB + HRVB

Model		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval	
Model	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit
Fixed	27	0.317	0.048	0.002	0.222	0.411	6.574	0.000		
Random	27	0.391	0.113	0.013	0.170	0.612	3.468	0.001	-0.670	1.452

Between-study		Other heterogeneity statistics			
Tau	TauSq	Q-value	df (Q)	P-value	I-squared
0.503	0.253	126.960	26	0.000	79.521

K-24

Cognitive function/ attention targeted vs not

Groups		Effect size and 95% confidence interval					Test of null (2-Tail)		Prediction Interval		Between-study		Other heterogeneity statistics			
Group	Number Studies	Point estimate	Standard error	Variance	Lower limit	Upper limit	Z-value	P-value	Lower limit	Upper limit	Tau	TauSq	Q-value	df (Q)	P-value	I-squared
Fixed effect analysis																
no	35	0.232	0.043	0.002	0.148	0.317	5.377	0.000					87.632	34	0.000	61.201
yes	11	0.596	0.087	0.008	0.425	0.767	6.830	0.000					145.070	10	0.000	93.107
Random effects analysis																
no	35	0.286	0.105	0.011	0.079	0.492	2.710	0.007	-0.841	1.412	0.549	0.301				
yes	11	1.007	0.195	0.038	0.626	1.389	5.174	0.000	-0.167	2.181	0.549	0.301				

Targeted k = 10 Nontargeted k - 23

Targets: post stroke, TBI, people working and/or tested under high performance stress