Title: Statistical Power and Swallowing Rehabilitation Research: Current Landscape and Next Steps

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Abstract:

Background: Despite rapid growth in the number of treatments to rehabilitate dysphagia, studies often demonstrate mixed results with non-significant changes to functional outcomes. Given that power analyses are infrequently reported in dysphagia research, it remains unclear whether studies are adequately powered to detect a range of treatment effects. Therefore, this review sought to examine the current landscape of statistical power in swallowing rehabilitation research.

Methods: Databases were searched for swallowing treatments using instrumental evaluations of swallowing and the penetration-aspiration scale as an outcome. Sensitivity power analyses based on each study's statistical test and sample size were performed to determine the minimum effect size detectable with 80% power.

Results: Eighty-nine studies with 94 treatment comparisons were included. Sixty-seven percent of treatment comparisons were unable to detect effects smaller than $d = 0.80$. The smallest detectable effect size was $d = 0.29$ for electrical stimulation, $d = 0.49$ for postural maneuvers, $d = 0.52$ for non-invasive brain stimulation, $d = 0.61$ for combined treatments, $d = 0.63$ for respiratory-based interventions, $d = 0.70$ for lingual strengthening, and $d = 0.79$ for oral sensory stimulation.

Conclusions: Dysphagia treatments examining changes in penetration-aspiration scale scores were generally powered to reliably detect larger effect sizes and not smaller (but potentially clinically meaningful) effects. These findings suggest that non-significant results may be related to low statistical power, highlighting the need for collaborative, well-powered intervention studies that can detect smaller, clinically meaningful changes in swallowing function. To facilitate implementation, a tutorial on simulation-based power analyses for ordinal outcomes is provided (https://osf.io/8sc5e/).

Introduction

The field of dysphagia has experienced rapid growth in the number and types of treatments to rehabilitate swallowing dysfunction. Despite these scientific advances, studies examining the effectiveness of these treatments often yield mixed results with non-significant changes to functional outcomes. These null findings are often associated with a lack of evidence for an intervention, prompting some to question their efficacy (1,2). However, clinically meaningful findings do not always align with statistical significance (3). Non-significant results may be attributed to inadequate statistical power to detect smaller, but potentially clinically meaningful, treatment effects. Statistical power is defined as the probability of detecting a "true" effect (when the effect exists) and involves four parameters in its analysis: power, alpha level, effect size, and sample size.

In the context of dysphagia rehabilitation, there are several swallowing-specific factors that should motivate researchers to design studies that can detect smaller treatment effects. First, dysphagia can be impacted by multiple, complex mechanisms of dysfunction, which may also vary within and between patient populations; therefore, it is unlikely that one treatment alone will result in a large effect. Secondly, bolus, task, and disease characteristics may increase swallowing variability, which can substantially reduce statistical power (4–6). Finally, effect sizes become increasingly smaller as the number of factors that influence a behavior increases (7); thus, dysphagia interventions seeking to improve functional outcomes in patients with multiple underlying mechanisms of dysfunction will require study designs, analyses, and sample sizes that have a high likelihood of detecting smaller effects. To confidently evaluate the ability of interventions to improve swallowing function, studies will require sufficient statistical power to detect a range of clinically meaningful effect sizes.

Though statistical power is often recommended to be 80%, this threshold is arbitrary and results in missing a "true" treatment effect 1 in 5 times (8). Power is not a binary classification (e.g., "well-powered" versus "underpowered"); instead, it exists on a curve, affording varying degrees of power depending on the effect size of interest (9,10). For example, a study may have 90% power to detect a 'large' effect (e.g., $d = 1.20$) but only 40% power to detect a smaller magnitude effect (e.g., $d = 0.30$). Additionally, it is important to understand that power extends beyond merely the number of participants collected and is specific to a study's design and

77 statistical analysis, such that certain designs (e.g., within- versus between-subject) and analyses
78 (e.g., parametric versus non-parametric) afford higher statistical power (11).
79 There has been an increased awareness of the prevalence and impact of low-powered
80 studies across many disciplines because of the importance of reproducibility and minimizing
81 error (12–14). Statistical power affects one's ability to accurately detect and estimate the
82 direction and magnitude of an effect, which impacts the reliability of research findings (15).
83 Studies with low power are not only less likely to detect an effect, but also have a higher false
84 positive rate when a statistically significant result is reported (12,16,17). This means that studies
85 with low power may mistakenly make a 'false discovery', indicating that a treatment effect is
86 present when there is no true treatment effect. The effect size estimate can also be inflated in
87 low-powered studies, overestimating its true magnitude (18). This overestimation is most notable
88 in studies with less than 50% power to detect a true effect (15). These errors contribute to
89 publication bias and affect reproducibility, often resulting in different conclusions across studies
90 (19).
91 It remains unclear whether swallowing rehabilitation research demonstrates adequate
92 statistical power to detect a range of treatment effects. Given recent findings that only 9% of
93 studies using the penetration-aspiration scale reported a power analysis, studies may not be
94 appropriately powered to detect treatment effects with this outcome (20). Therefore, this review
95 aimed to examine the current landscape of statistical power in swallowing rehabilitation
96 research. Since statistical power is unique to a given research question and analysis, we chose to
97 investigate studies examining changes to the penetration-aspiration scale – an outcome measure
98 with widespread clinical and research use in the field of dysphagia (21). The minimum effect
99 size detectable with 80% power was then calculated for each study. Across all studies, we used a
100 common effect size metric, namely Cohen's *d*, to describe the relative sensitivity of swallowing
101 rehabilitation research to detect a range of effects. Notably, these effect sizes do not reflect each
102 study's results; instead, they indicate the minimum effect size that was detectable with 80%
103 power given the study design, sample size, and analysis. In this sense, studies with higher
104 statistical power have a greater likelihood to detect smaller effect sizes.
105
106 **Methods**
107 **Search Strategy**

The search strategy was conducted in September 2021 according to PRISMA guidelines (22). Two databases (Web of Science and PubMed) were queried for peer-reviewed publications citing "A Penetration-Aspiration Scale" (21) in order to identify studies using this outcome. Relevant systematic reviews and meta-analyses were also searched. For inclusion in the review, studies needed to have been interventions on adult populations (≥ 18 years of age) using the penetration-aspiration scale as an outcome measure during instrumental assessments of swallowing (flexible endoscopic evaluations of swallowing or videofluoroscopic swallowing studies). Exclusion criteria included studies descriptively reporting penetration-aspiration scale results without statistical analysis, non-English articles, pediatric populations, surgical treatments, and compensatory strategies (e.g., chin tuck, bolus modifications). Case series with less than 4 participants were also excluded since analyses with these sample sizes are typically descriptive in nature. Studies that did not provide sufficient information to calculate the minimum effect size detectable were excluded.

Study Selection & Data Abstraction

After removal of duplicates, titles and abstracts were screened for inclusion. Full-text articles were then assessed for final inclusion. The following variables were extracted from each article: treatment type, sample size, patient population, study design, whether a power analysis was reported, type of statistical analysis and comparison (i.e., between versus within-subject), comparison *p*-value, and alpha level. A conservative approach to power estimation was used, such that the statistical test and sample size from the comparison that afforded the highest power was chosen. For example, if a study performed both between- (i.e., experimental vs control group) and within-subject (i.e., pre- to post-intervention for the experimental group) comparisons with the penetration-aspiration scale then the statistical test and sample size for the comparison that provided the highest power was used. Sensitivity analyses did not include additional covariates (e.g., bolus consistency, age).

Statistical Analysis

Sensitivity power analyses were performed in R version 4.0 for parametric statistical tests (23) and G*Power version 3.1 for non-parametric tests (24). Despite strict statistical assumptions imposed in G*Power (i.e., normal distribution of difference scores for the Wilcoxon signed-rank

test), we decided to use this software given its prevalence in clinical research. Sensitivity power analyses were performed based on the statistical test, sample size, and alpha level to determine the minimum effect size detectable with 80% power. Effect sizes were calculated based on the statistical test performed, then converted to Cohen's *d* to provide a standardized measure of effect size across studies. Though Cohen's *d* is an effect size measure for continuous outcomes and is not recommended for ordinal outcomes (e.g., the penetration-aspiration scale), we used this effect size since most studies reported Cohen's *d*. Thus, this reduced the number of effect size conversions and provided a common metric for comparisons across highly heterogeneous studies. Given that studies did not consistently report correlations between pre- and post-treatment outcomes for within-subject comparisons, a "moderate" correlation was assumed when converting from Cohen's *dz* to Cohen's *d*. The following formula was used for this conversion, where $\rho = 0.50$ (25).

$$d = dz \times \sqrt{2 \times (1 - \rho)}$$

Cohen's *d* represents a standardized mean difference, which is calculated by dividing the difference in means by sources of variation. These values can then be interpreted as a percentage of the standard deviation; for example, a Cohen's *d* value of 0.50 means the difference between two groups equals half a standard deviation (26). Though conventional guidelines for "small" ($d = 0.20$), "medium" ($d = 0.50$), and "large" ($d = 0.80$) effect sizes were used to provide a general framework for the magnitude of effects that studies were adequately powered to detect (11), raw effect size values were also examined for more precise interpretation. In this review, these effect size values are presented in the context of each study's sensitivity (i.e., power) to detect a range of effects. Importantly, these values do not represent actual effect size results from these studies. Power-determination analyses were also performed across a range of effect sizes ($d = 0.1 – 1.0$) for each study.

Results

The database search resulted in 1298 studies from Web of Science, 630 studies from PubMed, and 9 from a manual search. Once duplicates were removed, 1376 unique studies remained (Figure 1). Five studies using multilevel models were excluded since the minimum effect size detectable with 80% power could not be calculated (27–31). Eighty-nine studies met inclusion criteria, including 39 surface or pharyngeal electrical stimulation (32–70), 14 non-

invasive brain stimulation (33,68,71–82), 14 respiratory (32,83–95), nine postural (96–104), six oral sensory stimulation (51,66,105–108), five lingual strengthening (109–113), and seven interventions with a combination of treatments (114–120). Five studies included two treatments (32,33,68,97,102); thus, the final number of treatment studies was 94. Fifty-nine studies were randomized controlled trials. The penetration-aspiration scale was the primary outcome of interest in most studies (56%), whereas 21% of studies indicated that it was a secondary outcome. The remaining 23% of studies did not explicitly state whether the penetration-aspiration scale was a primary or secondary outcome. Most (87%) treatment comparisons selected for sensitivity power analyses were within-subject statistical analyses. Eighty-six (91%) treatment comparisons used statistical analyses that provided Cohen's *d* as a measure of effect size, whereas only 3 comparisons used odds ratios (OR) and 5 used an effect size for chi-squared tests (φ). Fifty-nine (63%) treatment comparisons reported a statistically significant result (Table 1). Among studies without a power analysis, 8 studies qualitatively cited low power as a potential reason for a null finding.

Power analyses were reported in 21 studies and thresholds for power ranged from 60% – 90% (Table 1). Two treatment comparisons were powered to detect effect sizes smaller than $d = 0.50$ (Figure 2). The minimum detectable effect size across studies using a between-subject analysis was $d = 0.58$ for electrical stimulation, $d = 0.74$ for respiratory interventions, $d = 0.74$ for postural maneuvers, $d = 0.93$ for combined treatments, $d = 1.11$ for non-invasive brain stimulation, and $d = 1.15$ for oral sensory stimulation. For studies using a within-subject analysis, the minimum detectable effect size was $d = 0.29$ for electrical stimulation, $d = 0.49$ for postural maneuvers, $d = 0.52$ for non-invasive brain stimulation, $d = 0.61$ for combined treatments, $d = 0.63$ for respiratory interventions, $d = 0.70$ for lingual strengthening, and $d = 0.79$ for oral sensory stimulation. Sixty-seven percent of treatment comparisons were unable to detect effects smaller than $d = 0.80$ with adequate statistical power.

Discussion

Though a variety of treatments to rehabilitate swallowing dysfunction are available to clinicians, inconsistent conclusions across studies obfuscates clinical best practice. This literature is defined by mixed results which may be attributed to inadequate statistical power, affecting a researcher's ability to accurately detect and estimate treatment effects. The present review

suggests that swallowing rehabilitation research is generally powered to detect conventionally large effect sizes and not smaller (potentially clinically meaningful) effects, which may help to explain mixed findings commonly seen in the literature.

Treatments included in this review spanned various domains, including postural maneuvers, non-invasive brain stimulation, and respiratory-based interventions. Across all treatments, adequate sensitivity to detect effects less than $d = 0.50$ was extremely rare. Furthermore, most (67%) treatment comparisons only had sufficient power to detect conventionally 'large' effects (i.e., $d > 0.80$), suggesting that non-significant results may be related to inadequate statistical power to detect smaller, but potentially clinically meaningful, effects (Figure 2). For example, as revealed in this systematic review, non-invasive brain stimulation studies seeking to detect a treatment effect of $d = 0.70$ would have an average of 49% power, meaning that these studies would detect a true treatment effect less than half of the time. In addition to this low sensitivity to detect treatment effects, studies with low statistical power are also more likely to result in inaccurate effect size estimates (15).

Multiple mechanisms of dysfunction, including disordered laryngeal vestibule closure, tongue base retraction, or pharyngeal constriction, often contribute to impairments in functional swallowing outcomes (i.e., aspiration or pharyngeal residue). Regardless of whether a given treatment is designed to target one or many mechanisms of swallowing dysfunction, the multifactorial nature of dysphagia makes it such that a single treatment is unlikely to result in large functional improvements to swallowing. Therefore, power analyses that explicitly specify the smallest treatment effect size of interest (i.e., the minimum amount of change in an outcome that is meaningful for a study to detect) are imperative to ensure that a study is not only informative, but also falsifiable. This central component of study design and power analyses requires careful consideration to ensure clinically meaningful effects have a high likelihood of detection and accurate estimation given the complex nature of dysphagia.

Rehabilitation research poses significant challenges to one of the most conventional methods of increasing statistical power in treatment studies – the recruitment of large patient samples. Barriers that prohibit merely increasing the sample size include, but are not limited to, the financial and ethical burden of large-scale clinical trials, the rarity of many diseases which result in dysphagia, and heightened variability between and within patient populations (121). In order to reduce the impact of these barriers, non-conventional analyses and study designs, such

as one-tailed statistical tests, multilevel models, and sequential designs, have been proposed as alternative approaches to increase power (122,123).

Though one-tailed tests are not common practice in the field of dysphagia, when specified a priori they can be a valid approach to maximize statistical power. One-tailed tests are beneficial if an effect is hypothesized to exist in only one direction and the opposite direction is not interesting nor expected. To achieve 80% power, a two-sided test would require a 20% larger sample size compared to a one-sided test. In this sense, one-sided statistical tests maximize data collection efficiency (124). For example, in one of the studies included in this review, Ludlow and colleagues used a one-tailed t-test with a sample size of 8 participants (61), which afforded a minimum detectable effect size of $d = 0.98$ compared to $d = 1.16$ with a two-sided approach.

Multilevel models, also known as mixed effects or hierarchical models, are another approach to potentially increase statistical power (125); however, they are rarely utilized in the dysphagia treatment literature (five out of 99 studies in this review). Whereas common statistical tests (e.g., t-tests, ANOVA, etc.) require aggregating multiple trials of an outcome to ensure a single data point represents each participant, multilevel models avoid aggregation. This effectively increases the sample size by including repeated trials while also allowing for analyses at the participant level.

Sequential analyses are a common approach in medical trials to optimize data collection efficiency (e.g., (126)). In this design, an a priori power analysis is performed and various data analysis time points (e.g., interim analysis) are prespecified with explicit methods to control the type 1 error rate (123). A major benefit is that data collection can often be stopped early (i.e., before the sample size specified in the power analysis is reached) given a reasonably high chance of observing a statistically significant finding after collecting less than half of the sample size (123). Though this type of design is beneficial for investigating whether a treatment effect might exist, effect sizes obtained from interim analyses are subject to the same small sample bias as underpowered studies and may require adjustments or follow-up studies to obtain an accurate effect size estimate (127).

Though power analyses were only reported in 20% of studies in this review, many qualitatively cited “low statistical power” as a reason for obtaining a null finding. However, none of these studies provided a quantitative analysis of the sensitivity of the study design and data to detect a treatment effect. Sensitivity power analyses are one approach to enhance one’s

understanding of the range of treatment effect sizes that could be reliably detected with an analysis, improving the interpretation of null findings. A sensitivity power analysis is dependent on the statistical analysis approach and provides the minimum detectable effect size given the desired level of power, alpha level, and sample size. For example, if a sensitivity power analysis reveals that a study has 80% power to detect $d = 0.40$ yet finds a non-significant result, then treatment effects larger than $d = 0.40$ are unlikely and treatment effects lower than $d = 0.40$ are possible, but the study design was insufficient to detect them. A major benefit of sensitivity power analyses is that they do not increase researcher burden since they can be performed after data are collected. This type of power analysis implicitly recognizes that resources are limited, and sample size is often based on feasibility constraints. Though sensitivity power analyses can be easily performed for common statistical tests with current software (e.g., (24,128)), multilevel models require a Monte Carlo simulation approach (129). A lack of software to perform these simulation-based power analyses, particularly with ordinal outcomes, is a substantial barrier for clinical researchers. Therefore, we have provided a brief supplemental tutorial for simulation-based power analyses with ordinal outcomes for both non-parametric tests (Mann-Whitney *U* and Wilcoxon signed-rank tests) and mixed effects (cumulative link) models (https://osf.io/8sc5e/).

A common approach to reconcile multiple treatment studies with mixed findings is to perform a systematic review. These reviews attempt to synthesize available evidence, ultimately providing an assessment of a treatment's efficacy. However, systematic reviews rarely acknowledge statistical power. If underpowered studies predominate, then conclusions based solely on the number of studies that reported a statistically significant result will be biased. An alternate approach is to combine studies in a meta-analysis to provide an overall summary effect. In the field of dysphagia; however, this approach is often untenable due to substantial heterogeneity in study design, patient populations, statistical analyses, assessment types, and swallowing tasks. Furthermore, direct replication studies are exceedingly rare. These barriers prohibit implementing rigorous meta-analyses to inform patient care. One potential solution which has garnered interest in other fields is open data sets (130). This not only ensures transparency and reproducibility, but also facilitates meta-analyses. Data sharing provides substantial benefits to the research community, most notably in the presence of mixed results, heterogenous studies, and a growing knowledge base.

There are several limitations to acknowledge in this review. Our results are specific to the penetration-aspiration scale. We acknowledge that interventions may not have been powered or designed to target this outcome. Instead, other outcomes may have been more appropriate given a study's research question. We chose the penetration-aspiration scale as our outcome of interest due to its widespread use in dysphagia management, which permitted inclusion of a large number of studies. Prior studies examining statistical power within a given field have used the summary effect size from meta-analyses as the "true effect" in their power analysis (12,131). However, this approach was not feasible in the dysphagia treatment literature due to a low number of meta-analyses. Furthermore, meta-analysis estimates from studies with predominantly low power may not reflect the true population effect. Instead, we used an approach to detect the sensitivity of each study by determining the minimum effect size detectable with 80% power. We used Cohen's *d* as the measure of effect size to summarize sensitivity across studies but acknowledge that conversion between effect sizes may affect their interpretation. Additionally, we assumed a "moderate" correlation for time points for within-subject statistical tests (e.g., Wilcoxon signed rank-test) and acknowledge that different magnitudes of within-subject correlations across studies may have affected our effect size estimates from sensitivity power analyses. However, studies did not commonly report this correlation which prohibited uniformly incorporating it into our analyses. Studies included in this review included diverse methodologies and analyses which may have affected their sensitivity to detect effects, such as the type of statistical test, level of comparison, alpha level, and statistical use of the penetration-aspiration scale (i.e., interval, ordinal, or categorical). Since we used an approach that maximized the sensitivity of each study, this may have overestimated statistical power, most notably in situations where parametric analyses (i.e., Cohen's *d*) were used. However, we were unable to perform re-calculations with appropriate statistical analyses without access to the original data. We used conventional guidelines for "small", "moderate", and "large" Cohen's *d* when interpreting minimum detectable effect sizes, though we recognize that these benchmarks are relative concepts and fully dependent on one's subfield, research context, and the smallest effect size of interest. The use of these effect size benchmarks may result in misrepresentation of the smallest effect size of interest for a given study's primary aim and outcome of interest. However, understanding the smallest effect size of interest for each study is not necessary to evaluate power across swallowing rehabilitation research. Future research will be necessary to better

define clinically significant change in swallowing outcomes in order to inform meaningful effect sizes for power analyses.

Conclusions

Though statistical power is a central component of study design, power analyses are infrequently reported in swallowing rehabilitation research. The current review suggests that swallowing interventions examining the penetration-aspiration scale are generally powered to only reliably detect larger effect sizes, whereas smaller (but potentially clinically meaningful) effects have a low likelihood of detection. These findings may help to explain mixed results commonly seen in the dysphagia treatment literature. Non-conventional study designs and statistical analyses may be important considerations to increase power in smaller samples. To promote higher levels of evidence in the context of meta-analysis, open data sets and transparent reporting may also improve the quality of inferences. Moving forward, a comprehensive understanding of clinically meaningful change in swallowing outcomes should be a priority to not only assist in sample size justifications, but also to ensure falsifiable and impactful findings that inform clinical practice.

Figure 1: PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) flow diagram

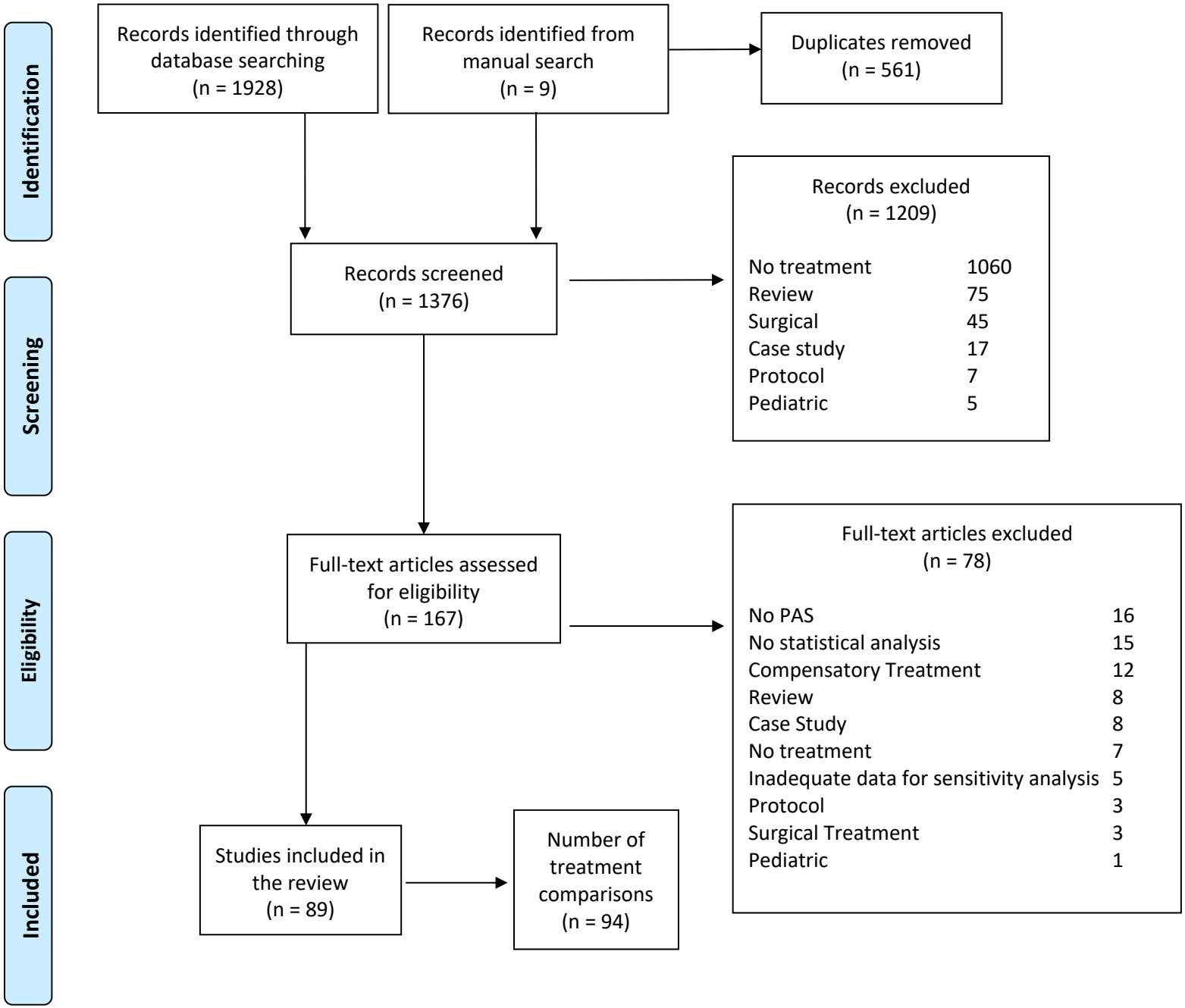
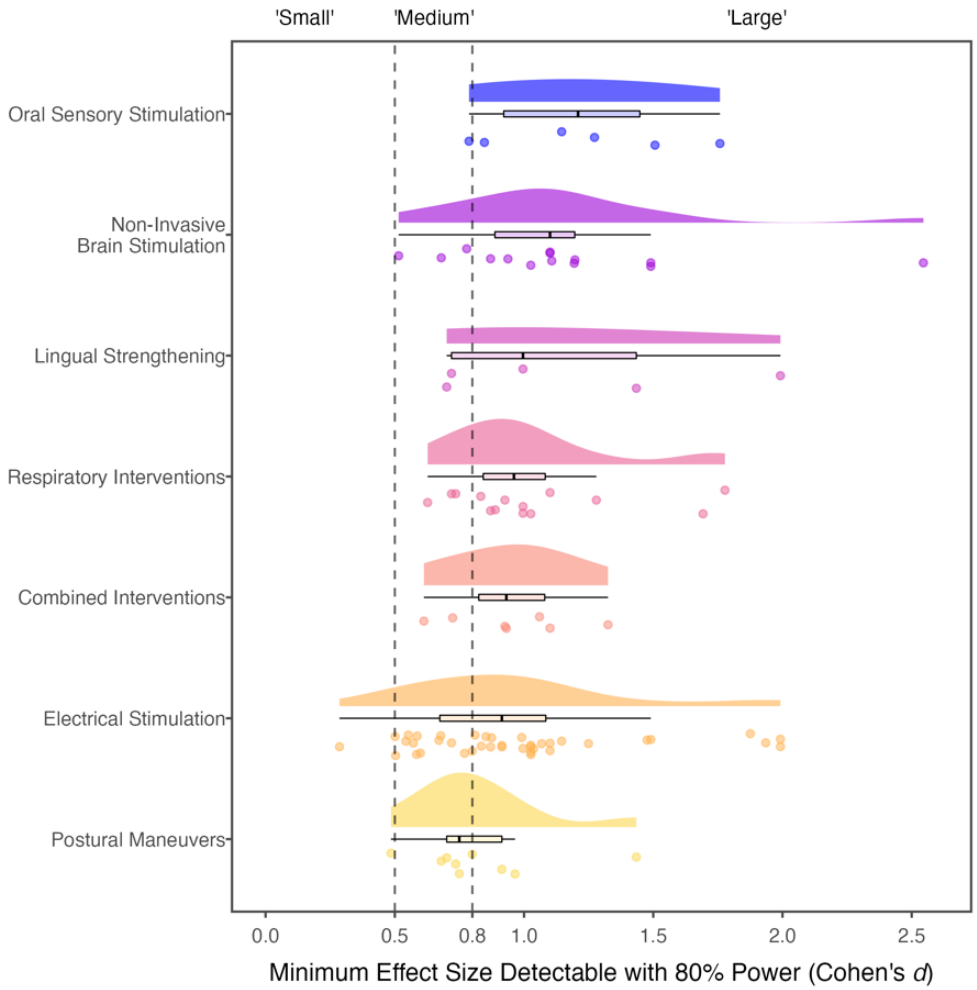


Figure 2: Minimum Effect Size Detectable with 80% Power Across Treatments



Note:
[1]The ability of a study to detect smaller effect sizes is desired.
[2]Cohen's *d* conventional benchmarks (i.e., "small", "medium", and "large) are provided for general interpretation. However, these guidelines are relative concepts and depend on clinical significance in the context of a given research question.

Table 1: Descriptive Statistics & Sensitivity Power Analyses

Electrical Stimulation								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power
Arreola, 2021	Stroke	RCT (89)	Wilcoxon signed rank test	Within-subjects	30	Ordinal	Yes (80%)	0.54
Bath, 2016	Stroke	RCT (129)	Repeated measures ANOVA	Between-subjects	126	Interval	Yes (90%)	0.50
Bath, 2020	Neurogenic	Observational (236)	Paired t-test	Within-subjects	98	Interval	Yes (80%)	0.29
Bhatt, 2015	Head and neck cancer	Observational Retrospective (95)	Independent samples t-test	Between-subjects	54 (experimental), 41 (control)	Interval	No	0.59
Bogaardt, 2009	Multiple sclerosis	Observational (25)	Wilcoxon signed rank test	Within-subjects	25	Ordinal	No	0.60
Everton, 2021	Stroke	RCT (72)	Independent samples t-test	Between-subjects	38 (experimental), 34 (control)	Interval	No	0.67
Gallas, 2010	Stroke	Observational (11)	Repeated measures ANOVA	Within-subjects	11	Interval	No	1.86
Guillen-Sola, 2017	Stroke	RCT (62)	Chi-square test	Between-subjects	17 (experimental), 17 (control)	Categorical (1-5, 6-8)	No	1.25

Hagglund, 2020	Stroke	RCT (32)	Wilcoxon signed rank test	Within-subjects	18	Ordinal	Yes (80%)	0.72
Huang, 2014	Stroke	RCT (29)	Repeated measures ANOVA	Within-subjects	10	Ordinal	No	1.99
Jayasekeran, 2010	Stroke	RCT (50)	Mann-Whitney U test	Between-subjects	22 (experimental), 28 (control)	Ordinal	Yes (80%)	0.83
Jeon, 2020	Stroke	RCT (34)	Repeated measures ANOVA	Within-subjects	17	Interval	Yes (80%)	0.99
Ko, 2016	Stroke and traumatic brain injury	Observational (28)	Repeated measures ANOVA	Within-subjects	12	Interval	No	1.94
Langmore, 2015	Head and neck cancer	RCT (116)	Repeated measures ANCOVA	Within-subjects	54	Interval	No	0.50
Lee, 2015	Heterogenous	Observational (15)	Wilcoxon signed-rank test	Within-subjects	15	Ordinal	No	0.80
Lee, 2019	Stroke	RCT (40)	Wilcoxon signed-rank test	Within-subjects	20	Ordinal	No	0.68
Lee, 2021	Stroke, brain tumor, encephalitis	RCT (49)	Paired t-test	Within-subjects	26	Interval	Yes (80%)	0.57
Lim, 2009	Stroke	RCT (28)	Wilcoxon signed-rank test	Within-subjects	16	Ordinal	No	0.77
Lim, 2014	Stroke	RCT (47)	Mann-Whitney U test	Between-subjects	18 (experimental), 15 (control)	Ordinal	No	1.04

Lin, 2011	Head and neck cancer	RCT (20)	Paired t-test	Within-subjects	10	Interval	No	1.00
Ludlow, 2007	Brain injury, cardiovascular disease, brain tumor, Parkinson's disease	Crossover Design (11)	Paired t-test	Within-subjects	10	Interval	No	0.85
Martindale, 2019	Stroke & non-stroke	Observational (43)	Repeated measures ANOVA	Within-subjects	43	Interval	No	0.88
Michou, 2014	Stroke	RCT (18)	Wilcoxon signed-rank test	Within-subjects	6	Ordinal	No	1.49
Miller, 2021	Stroke	RCT (12)	Wilcoxon signed-rank test	Within-subjects	12	Ordinal	No	0.91
Mituuti, 2018	Stroke	Observational (10)	Friedman's ANOVA	Within-subjects	10	Ordinal	No	1.99
Oh, 2019	Stroke	RCT (26)	Paired t-test	Within-subjects	14	Interval	No	0.81
Ortega, 2016	Older adults	RCT (38)	Chi-square test	Between-subjects	19 (experimental), 19 (comparison)	Categorical	No	1.15
Park, 2012	Stroke	RCT (18)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.10
Park, 2016	Stroke	RCT (50)	Paired t-test	Within-subjects	25	Interval	Yes (80%)	0.58

Park, 2018	Parkinson's disease	RCT (18)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.10
Park, 2019	Stroke	Observational (10)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	Yes (80%)	1.03
Restivo, 2013	Multiple sclerosis	RCT (20)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	No	1.03
Rofes, 2013	Stroke	RCT (20)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	No	1.03
Seo, 2021	Stroke	RCT (23)	Wilcoxon signed-rank test	Within-subjects	12	Ordinal	No	0.91
Simonelli, 2019	Stroke	RCT (31)	Mann Whitney U test	Between-subjects	16 (experimental), 15 (control)	Ordinal	No	1.07
Sun, 2013	Stroke	Observational (29)	Wilcoxon signed-rank test	Within-subjects	29	Ordinal	Yes (80%)	0.55
Terre, 2015	Traumatic brain injury	RCT (20)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	No	1.03
Vasant, 2016	Stroke	RCT (35)	Logistic regression	Between-subjects	35	Categorical (1-2, 3-8)	Yes (80%)	1.45
Verin, 2011	Stroke, multiple sclerosis, Parkinson's disease, progressive	Crossover Design (11)	Wilcoxon signed-rank test	Within-subjects	13	Ordinal	No	0.87

	supranuclear palsy							
Non-Invasive Brain Stimulation								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power
Khedr, 2019	Parkinson's disease	RCT (30)	Paired t-test	Within-subjects	19	Interval	Yes (80%)	0.68
Kim, 2011	Traumatic brain injury	RCT (30)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	No	1.03
Lee, 2015	Stroke	RCT (24)	Repeated measures ANOVA	Within-subjects	12	Interval	No	1.20
Lim, 2014	Stroke	RCT (47)	Mann-Whitney U test	Between-subjects	14 (experimental), 15 (control)	Ordinal	No	1.11
Lin, 2018	Stroke	RCT (28)	Wilcoxon signed-rank test	Within-subjects	13	Ordinal	Yes (80%)	0.87
Michou, 2012	Stroke	Observational (6)	Wilcoxon signed-rank test	Within-subjects	6	Ordinal	No	1.49
Michou, 2014	Stroke	RCT (18)	Wilcoxon signed-rank test	Within-subjects	6	Ordinal	No	1.49
Park, 2013	Stroke	RCT (18)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.10

Park, 2017	Stroke	RCT (33)	Paired t-test	Within-subjects	11	Interval	No	0.94
Park, 2019	Geriatric	Observational (8)	Wilcoxon signed-rank test	Within-subjects	8	Ordinal	No	1.19
Restivo, 2019	Multiple sclerosis	RCT (18)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.10
Unluer, 2019	Stroke	RCT (28)	Friedman's ANOVA	Within-subjects	15	Ordinal	Yes (80%)	0.78
Verin, 2008	Stroke	Observational (7)	Repeated measures ANOVA	Within-subjects	7	Interval	No	2.55
Zhong, 2021	Stroke	RCT (147)	Repeated measures ANOVA	Within-subjects	36	Interval	No	0.51
Respiratory Interventions								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power
Arnold, 2020	Stroke	Observational (20)	Paired t-test	Within-subjects	10	Interval	No	1.00
Eom, 2017	Stroke	RCT (26)	Wilcoxon signed-rank test	Within-subjects	13	Ordinal	Yes (60%)	0.87
Guillen-Sola, 2017	Stroke	RCT (62)	Chi-square test	Between-subjects	16 (experimental), 17 (control)	Categorical (1-4; 5-8)	No	1.28

Hegland, 2016	Stroke	Observational (12)	Repeated measures ANOVA	Within-subjects	12	Interval	No	1.78
Hutcheson, 2018	Head and neck cancer	Observational (64)	Wilcoxon signed-rank test	Within-subjects	23	Ordinal	Yes (90%)	0.63
Jang, 2019	Stroke	RCT (32)	Wilcoxon signed-rank test	Within-subjects	18	Ordinal	No	0.72
Martin-Harris, 2015	Head and neck cancer	Observational (30)	Test of Proportions	Within-subjects	30	Categorical	Yes (80%)	0.93
Mohannak, 2020	Inclusion Body Myositis	Observational (12)	Paired t-test	Within-subjects	12	Interval	No	0.89
Moon, 2017	Stroke	RCT (18)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.10
Park, 2016	Stroke	RCT (27)	Wilcoxon signed-rank test	Within-subjects	14	Ordinal	No	0.83
Pitts, 2009	Parkinson's disease	Observational (10)	Wilcoxon signed-rank test	Within-subjects	10	Ordinal	No	1.03
Plowman, 2016	ALS	Observational (15)	Repeated measures ANOVA	Within-subjects	15	Interval	No	1.69
Plowman, 2019	ALS	RCT (46)	Chi-square test	Between-subjects	23 (experimental), 23 (control)	Categorical (1-2, 3-8)	No	1.00
Troche, 2010	Parkinson's disease	RCT (60)	Repeated measures ANCOVA	Between-subjects	30 (experimental), 30 (control)	Interval	Yes (80%)	0.74

Combined Treatments								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power
Balou, 2019	Older adults	Observational (9)	Wilcoxon signed-rank test	Within-subjects	9	Ordinal	No	1.1
Furuie, 2019	Head and neck cancer	Observational (30)	Independent samples t-test	Between-subjects	30 (experimental), 30 (control)	Interval	No	1.06
Hsiang, 2019	Head and neck cancer	RCT (40)	Mann Whitney-U test	Between-subjects	20 (experimental), 20 (control	Ordinal	Yes (80%)	0.93
Kraaijenga, 2017	Head and neck cancer	Observational (17)	Paired t-test	Within-subjects	17	Interval	Yes (80%)	0.72
Tarameshlu, 2019	Multiple sclerosis	RCT (20)	Independent samples t-test	Between-subjects	10 (experimental), 10 (control	Interval	No	1.32
van der Molen, 2011	Head and neck cancer	RCT (49)	Wilcoxon signed-rank test	Within-subjects	24	Ordinal	No	0.61
van der Molen, 2014	Head and neck cancer	RCT (49)	McNemar test	Within-subjects	29	Categorical	No	0.93
Lingual Strengthening								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power

Kim, 2017	Stroke	RCT (35)	Paired t-test	Within-subjects	18	Interval	No	0.70
Namiki, 2019	Geriatric	Observational (18)	Wilcoxon signed-rank test	Within-subjects	18	Ordinal	Yes (80%)	0.72
Robbins, 2005	Geriatric	Observational (10)	Repeated measures ANCOVA	Within-subjects	10	Interval	No	1.99
Robbins, 2007	Stroke	Observational (10)	Paired t-test	Within-subjects	10	Interval	No	1.00
Steele, 2016	Stroke	RCT (11)	Friedman's ANOVA	Within-subjects	6	Ordinal	Yes (NR)	1.43
Postural Maneuvers								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported & Threshold	Minimum Cohen's *d* Detectable at 80% Power
Choi, 2017	Stroke	RCT (32)	Paired t-test	Within-subjects	16	Interval	Yes (60%)	0.75
Gao, 2017	Stroke	RCT (90)	Repeated measures ANOVA	Between-subjects	30 (experimental), 30 (control)	Interval	No	0.67
Kim, 2019	Stroke	RCT (25)	Wilcoxon signed-rank test	Within-subjects	12	Ordinal	Yes (60%)	0.91
Mano, 2015	Spinal and bulbar muscular atrophy	Observational (6)	Paired t-test	Within-subjects	6	Interval	No	1.43

Park, 2017	Stroke	RCT (37)	Paired t-test	Within-subjects	19	Interval	Yes (80%)	0.68
Park, 2018	Stroke	RCT (22)	Wilcoxon signed-rank test	Within-subjects	11	Ordinal	No	0.97
Park, 2019	Stroke	RCT (37)	Paired t-test	Within-subjects	18	Interval	Yes (80%)	0.70
Park, 2020	Stroke	RCT (20)	Wilcoxon signed-rank test	Within-subjects	15	Ordinal	Yes (60%)	0.80
Ploumis, 2018	Stroke	RCT (70)	Wilcoxon signed-rank test	Within-subjects	37	Ordinal	No	0.49
Oral Sensory Stimulation								
Author, Year	Patient Population	Study Design (Total Sample Size)	Statistical Approach	Comparison	Comparison Sample Size	PAS Treatment	Power Analysis Reported (Threshold)	Minimum Cohen's *d* Detectable at 80% Power
Jakobsen, 2019	Brain injury	RCT (10)	Wilcoxon signed-rank test	Within-subjects	5	Ordinal	No	1.76
Ortega, 2016	Older adults	RCT (38)	Chi-square test	Between-subjects	19 (experimental), 19 (comparison)	Categorical	No	1.15
Power, 2006	Stroke	RCT (16)	Repeated measures ANOVA	Within-subjects	8	Interval	No	1.51
Rosenbek, 1998	Stroke	RCT (45)	Paired t-test	Within-subjects	13	Interval	No	0.85

Tomsen, 2019	Older adults	RCT (28)	Paired t-test	Within-subjects	7	Interval	No	1.27

RCT: Randomized controlled trial, NR: Not reported, ANOVA: Analysis of variance, ANCOVA: Analysis of covariance

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