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Use of the Penetration-Aspiration Scale in Dysphagia Research: A Systematic Review

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Abstract
The penetration-aspiration scale (PAS) is an 8-point scale used to characterize the depth and response to airway invasion during videofluoroscopy. Though widely used in the field of deglutition, there is a lack of consensus regarding the statistical properties of the scale. In order to better understand the state of the literature and the statistical use of the PAS, a systematic review was undertaken to descriptively examine trends in statistical and reporting practices of the PAS since its inception. Online databases were searched for studies citing the original PAS article, which yielded 754 unique articles. Of these, 183 studies were included in the review. Results showed inconsistencies in the statistical use of the scale; 79 studies treated the PAS as ordinal, 71 as categorical, and 49 as interval. Ten types of categorizations were identified. Reporting of power analyses (9%), as well as inter- (26%) and intra-rater (17%) reliability, was uncommon. Among studies that administered multiple bolus volumes or consistencies, 55% reported PAS analyses at the participant/group level only. This review confirms the existence of discrepancies in the statistical treatment of the PAS. A lack of consensus among researchers limits comparisons between studies. The approach to handling this scale dictates the statistical tests used, potentially affecting results and interpretations. Consistent application of statistically sound approaches to PAS analyses is vital for the future of deglutition research.

Keywords Penetration-Aspiration Scale · Statistical analysis · Research trends · Deglutition

Background

The penetration-aspiration scale (PAS) is an 8-point scale used to characterize both the location of airway invasion events and a patient's response during videofluoroscopic swallowing studies [1] (Table 1). The scale has become a standard in the field of deglutition in both clinical practice and research. Recently, Steele and Grace-Martin [2] discussed the statistical properties, construct validity, and inherent constraints of the scale. Despite its widespread use, they note a lack of consensus in the statistical treatment of the scale, as well as additional considerations when reporting PAS scores, highlighting the complex and nuanced nature of this outcome measure.

The statistical properties of an outcome measure are an important factor in selecting a statistical test or model. In deglutition research, cases have been documented demonstrating variable treatment of the PAS [2], specifically as either a categorical, ordinal, or interval variable. A categorical variable contains unordered items that each represent a unique group or value (e.g., blood type). An ordinal variable is thought to have discrete, ordered categories in which the items represent increasing magnitude, without assumption of equal distance between units (e.g., symptom severity on a Likert scale). An interval variable represents an unlimited number of continuous values of increasing magnitude between a defined minimum and maximum limit (e.g., height, age) [3].

The PAS is a multidimensional scale, meaning that more than one type of event is judged. The scale was designed to capture three constructs: depth of airway invasion, material remaining after the swallow, and a patient's response to aspiration. The scale ranks depth of airway invasion as superordinate to other parameters [1]. Despite comprising distinct

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Table 1 Penetration-aspiration scale [1]

Score	Description
1	Material does not enter the airway
2	Material enters the airway, remains above the level of the vocal folds, and is ejected from the airway
3	Material enters the airway, remains above the level of the vocal folds, and is not ejected from the airway
4	Material enters the airway, contacts the vocal folds, and is ejected from the airway
5	Material enters the airway, contacts the vocal folds, and is not ejected from the airway
6	Material enters the airway, passes below the level of the vocal folds, and is ejected into the larynx or out of the airway
7	Material enters the airway, passes below the level of the vocal folds, and is not ejected out of the trachea despite effort
8	Material enters the airway, passes below the level of the vocal folds, and no effort is made to eject

categories ordered by depth of airway invasion, its statistical properties have been a topic of debate. McCullough et al. [4] conducted a clinician survey to examine its ordinal and interval properties. They demonstrated relative uncertainty among clinicians when ranking PAS score severity, calling into question the ordinal property of linearly increasing magnitude [4]. Specifically, clinicians rated a score of 3 as more severe than a 4 (87% of respondents) or 6 (58% of respondents), and a score of 5 as more severe than a 6 (71% of respondents). The requirement of equal distance between items for interval data was also called into question, given that unequal distances between scores was established [4]. Furthermore, each score on the scale represents a unique category quantifying depth of airway invasion, the location of material remaining after the swallow, and a sensory response to aspiration; thus, decimal places (e.g., 4.6) have no clinically interpretable meaning. Researchers may be inclined to treat the scale as interval with parametric assumptions, given that parametric statistical tests can afford greater statistical power than their non-parametric counterparts. However, this practice can potentially lead to the interpretation of small group differences as statistically significant in the absence of clinical significance.

In addition to careful consideration of data type and statistical methodology, the use of transparent reporting practices is essential for ensuring scientific rigor and assessing a study's results and implications. An outcome measure requires reliability testing to confirm its reproducibility. McCullough and colleagues [5] examined the inter- and intra-rater reliability of three experienced clinicians without formal training in rating airway invasion with the PAS. Poor inter-rater agreement was found, emphasizing the importance of conducting and reporting reliability testing and results. Hind et al. [6] also showed poor agreement among untrained raters on rare scores (PAS 4 and 5). Experienced clinicians have demonstrated poor inter-rater reliability when rating the temporal occurrence of penetration and aspiration (e.g., before, during, or after the swallow) without training [7], though temporal ratings of airway invasion are beyond the scope of the PAS. These studies suggest that training is both a requirement for raters and an integral element of transparent reporting methodologies, as originally specified by Rosenbek et al. [1].

An additional consideration when using the PAS in research is related to the study protocol, specifically how to represent and analyze the number of boluses presented, as well as their volume and rheological characteristics. Study protocols often result in multiple PAS scores per participant across several boluses. Researchers must decide whether statistical analyses will be performed on an aggregate of boluses (e.g., by reporting only the worst PAS score across boluses) or individually analyzed by bolus volume and consistency conditions. Trends in such reporting practices are currently unknown.

Clearly, there are many decisions that must be made when implementing the PAS in research, from protocol design to statistical analysis. These decisions have implications for the results and interpretations of findings in deglutition research. A better understanding of how the PAS is currently used in dysphagia research, and how its use has evolved over time will clarify the current state of PAS reporting practices and guide implementation of valid and standardized PAS analysis in the future. The purpose of this systematic review was to descriptively examine trends in the statistical use of the PAS since its inception. We also examined the frequency of categorization methods, reporting of PAS results by bolus condition, reporting of reliability and power analyses, and geographic variations in the scale's use.

Methods

Search Strategy

The study selection process was conducted according to The Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) guidelines [8]. A systematic search was performed in July 2018 for citations of "A Penetration-Aspiration Scale" [1] in two online databases: World of Science and PubMed. This search strategy was employed to ensure

high specificity of retrieved articles that explicitly cited the original PAS article.

Inclusion and Exclusion Criteria

Inclusion criteria included original research articles using the PAS as an outcome measure for statistical analysis during videofluoroscopy. Exclusion criteria included studies descriptively reporting PAS results without statistical analysis, non-videofluoroscopic evaluations (e.g., manometry, FEES), studies modifying the PAS (e.g., cumulative PAS scores) or examining only a subset of the scale (e.g., PAS 2–5 only), non-English articles, pediatric populations, and case studies.

Study Selection and Data Abstraction

After removal of duplicates, the first author screened all abstracts for inclusion. The second author screened 20% of these abstracts for inter-rater reliability to determine whether each study met inclusion and exclusion criteria. Excellent agreement was obtained between raters (92% agreement, Cohen's $\kappa = 0.82$). Given the limited number of disagreements, abstracts that did not meet agreement were included for full-text review. Full-text articles were assessed for final inclusion. Inter-rater reliability for full-text inclusion was performed on 20% of the articles (98% agreement, Cohen's $\kappa = 0.97$) and disagreements were resolved by consensus. Variables abstracted from articles meeting final inclusion in the review were the following: study treatment of the PAS (interval, categorical, ordinal), type of categorization (if categorical PAS treatment was used; e.g., scores of 1–2 compared to scores of 3–8), level of analysis (participant/group or bolus condition), inclusion of inter- and intra-rater reliability, inclusion of a power analysis, and geographic location of the corresponding author. The PAS data type was determined by examining the methodology of each study, with particular focus on the statistical test(s) used with the PAS as the dependent variable. Statistical tests require inherent assumptions about the data they describe; therefore, our first step in determining the PAS data type was identifying the statistical test used for analysis. For example, studies using analyses such as a chi-squared test or logistic regression were defined as categorical, whereas parametric analyses, including t-tests, ANOVA, or linear regression, were defined as interval. Studies using non-parametric analyses such as the Mann-Whitney U test, Wilcoxon Signed Rank Test, and Spearman correlations were defined as ordinal. Since non-parametric statistical tests can be used with both ordinal and interval variables under certain conditions (e.g., small sample size, non-normal distribution), we also identified the type of descriptive PAS reporting in studies that used these tests (e.g., mean, median) to further clarify how the PAS was treated. Studies often included multiple analyses with the PAS as an outcome measure. In these cases, each analysis was examined separately for its statistical properties. For example, it was possible for the PAS to be treated as both categorical and interval within a single study. Inter-rater agreement of the statistical use of the PAS was performed on 20% of articles (94% agreement, Cohen's $\kappa = 0.90$).

Results

The database search yielded 754 unique articles (Fig. 1). Of these, 183 articles were determined to meet final inclusion and exclusion criteria. The majority (88%) of articles employed prospective study designs with a median sample size of 40 (range: 7–397).

Seventy-nine studies treated the PAS as ordinal [9–87], 71 as categorical [15, 17, 18, 30, 34, 39, 50, 53, 71, 73, 77, 79, 88–146], and 49 as interval [117, 125, 128, 145, 147–191] (Fig. 2). Sixteen studies used multiple statistical analyses with the PAS [15, 17, 18, 30, 34, 39, 50, 53, 71, 73, 77, 79, 117, 125, 128, 145]. Among studies treating the scale as an ordinal variable with non-parametric statistical analyses, 47% used mean PAS scores when descriptively reporting results [10, 11, 17–19, 22, 24–27, 32–34, 37, 40–42, 44, 47, 48, 53–64, 68, 70, 71, 83, 84]. Categorization has surpassed ordinal analyses in recent years (Fig. 3). Within studies identified as using the PAS as a categorical variable, 4 studies categorized the PAS differently for separate analyses [123, 125, 137, 145]. Ten types of categorizations were identified, most of which were binary with the exception of 4 instances (Fig. 4). Common categorizations included PAS 1–2 versus 3–8, 1–5 versus 6–8, and 1 versus 2–8 (see Table 2 for full list of categorization methods).

Twenty-two different countries were represented across the included studies, with the majority of articles (43%) from the United States, followed by Korea (23%), and Australia (7%; see Fig. 5 for full list of countries). Power analyses were reported in 9% of studies [12, 18, 20, 22, 37, 39, 42, 78, 97, 115, 126, 134, 146, 149, 174, 187]. Inter- and intra-rater reliability of PAS ratings were performed in 26% and 17% of studies, respectively (see Table 3 for full list of studies reporting reliability and power analyses). Sixty-eight percent of studies reported using multiple bolus volumes or consistencies in their videofluoroscopy protocol, whereas 9% did not report the types of boluses administered. Among studies with protocols involving multiple bolus volumes and/or consistencies, 55% reported PAS analyses at the participant/group level only [14, 15, 21, 23, 29–31, 33, 34, 37, 44, 48, 54, 62, 63, 68, 70, 71, 73, 74, 76, 77, 79, 84, 86, 93, 95, 96, 98–100, 102–104, 106–108, 111, 112, 121, 123, 124, 126–128, 130, 136, 138, 144, 145, 147, 149, 151, 153–156, 163, 164, 167, 170, 175, 177–179, 181, 185, 189, 190].

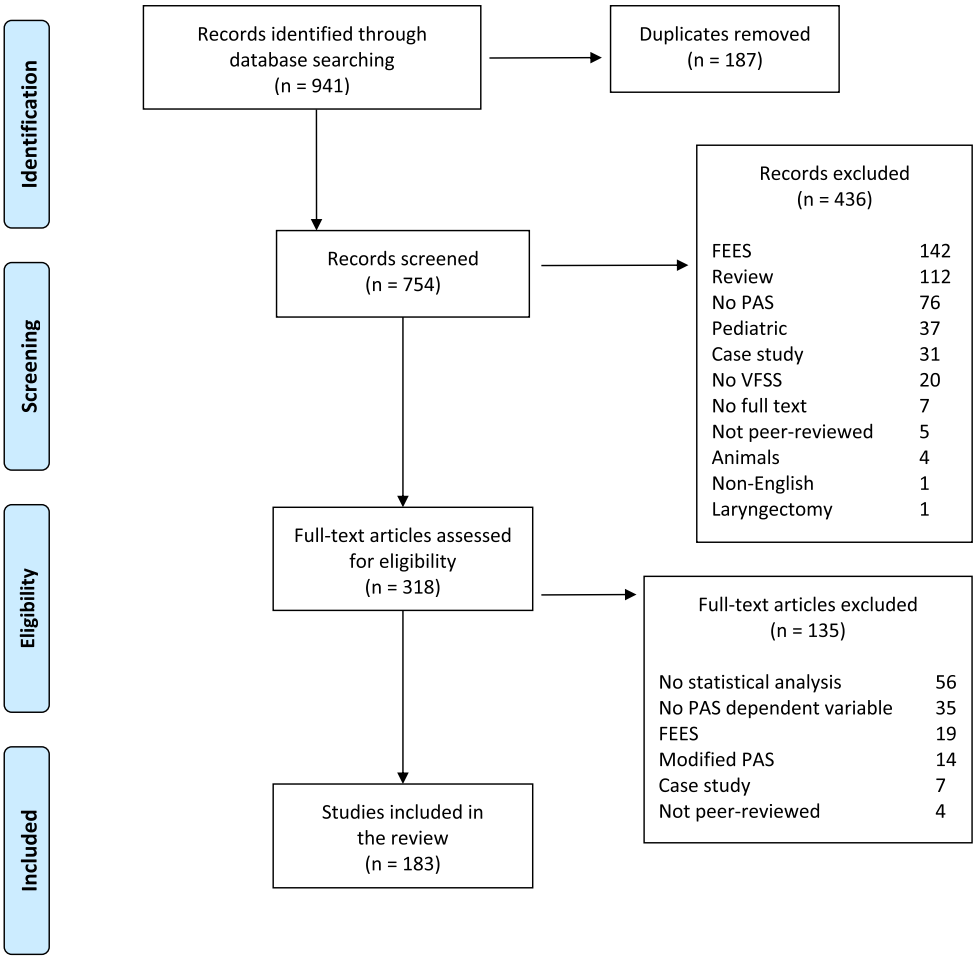

Fig. 1 PRISMA (Preferred reporting items for systematic reviews and meta-analyses) flow diagram

Discussion

The PAS is a useful tool to describe airway invasion events during videofluoroscopic swallowing studies. Its widespread use in research illustrates its utility as an outcome measure and its ease of clinical translation. This review confirms the existence of discrepancies in the statistical use of the PAS across deglutition research. Though the scale's statistical properties have previously been discussed [2, 4], discrepancies within the literature limit one's ability to synthesize and compare results across studies. Ongoing discussion regarding best statistical practices is clearly warranted.

Our results revealed that non-parametric tests assuming ordinal data properties are preferred for PAS analysis. This is likely due to the scale's non-normal distribution and potential violations of assumptions that are required for parametric analyses. Interestingly, 47% of studies with non-parametric analyses used means to descriptively report the PAS, rather than the median. Means are typically used to describe interval data, for which between-value fractions are meaningful, whereas medians are more suited to ordinal, ranked data. Thus, in studies that utilized non-parametric analyses, it is somewhat surprising for mean PAS scores to be reported concurrently.

In terms of trends over time, ordinal analyses have generally predominated; however, PAS categorization has increased in popularity in recent years. Our results showed variations in how researchers choose to delineate categorical boundaries along the 8-point scale. Though we acknowledge that categorization of the PAS should be grounded in one's research design and questions, we also recognize that categorical boundaries must be supported by a physiologic framework. For example, research studies examining "normal" and "abnormal" airway invasion should account for research demonstrating that transient penetration (e.g., PAS 2) is prevalent in healthy populations and considered a variant of normal [69, 147]. Thus, it is encouraging to see that PAS scores of 1–2 versus 3–8 represented the most common categorization type.

Among studies that reported multiple bolus volumes and consistencies in their videofluoroscopy protocols, a minority (45%) reported PAS results by bolus condition. Both bolus volume [192, 193] and consistency [39, 83, 193, 194] can alter the depth and sensory response to airway invasion

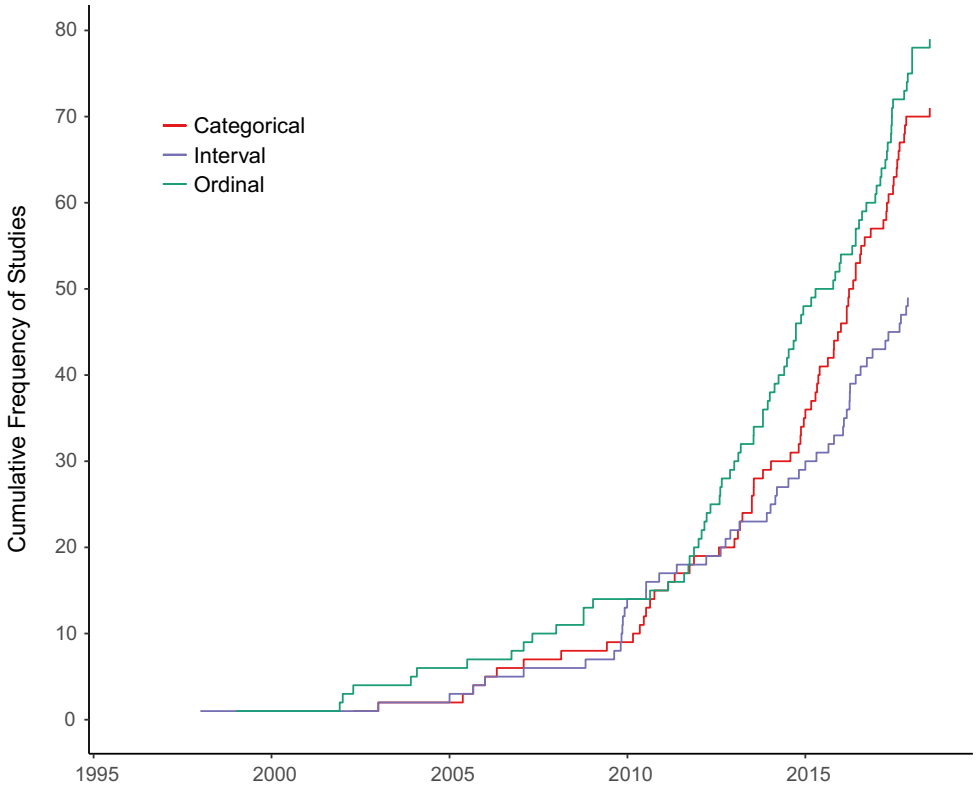

Fig. 2 Statistical analysis of the penetration-aspiration scale across time

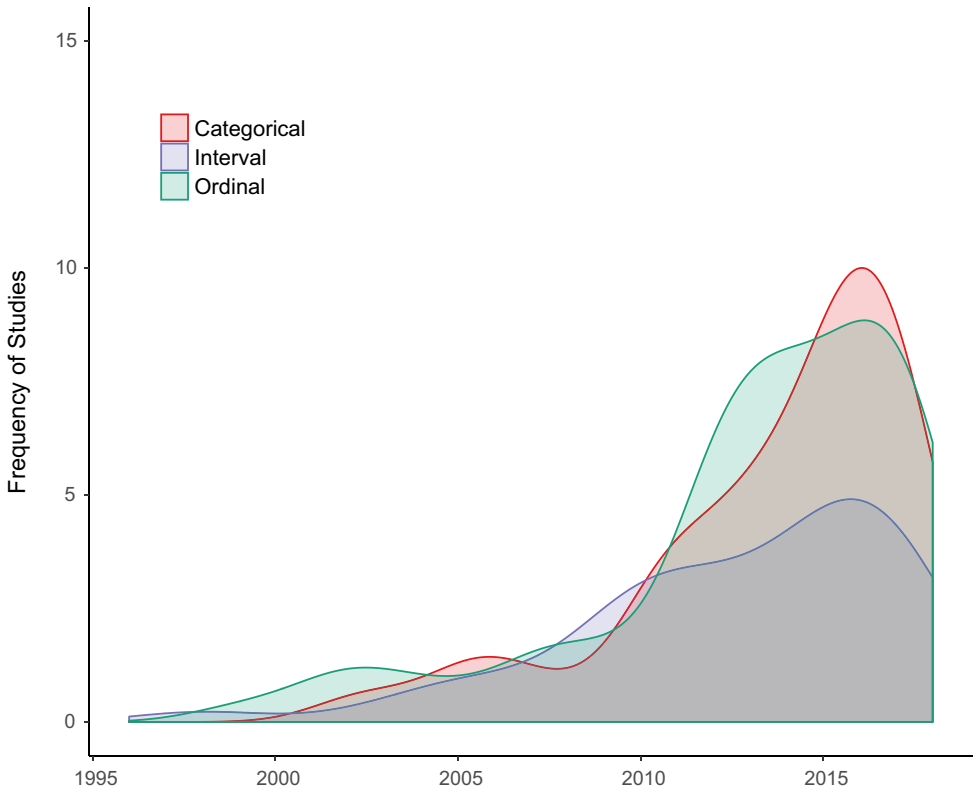

Fig. 3 Annual changes in the statistical analysis of the penetration-aspiration scale

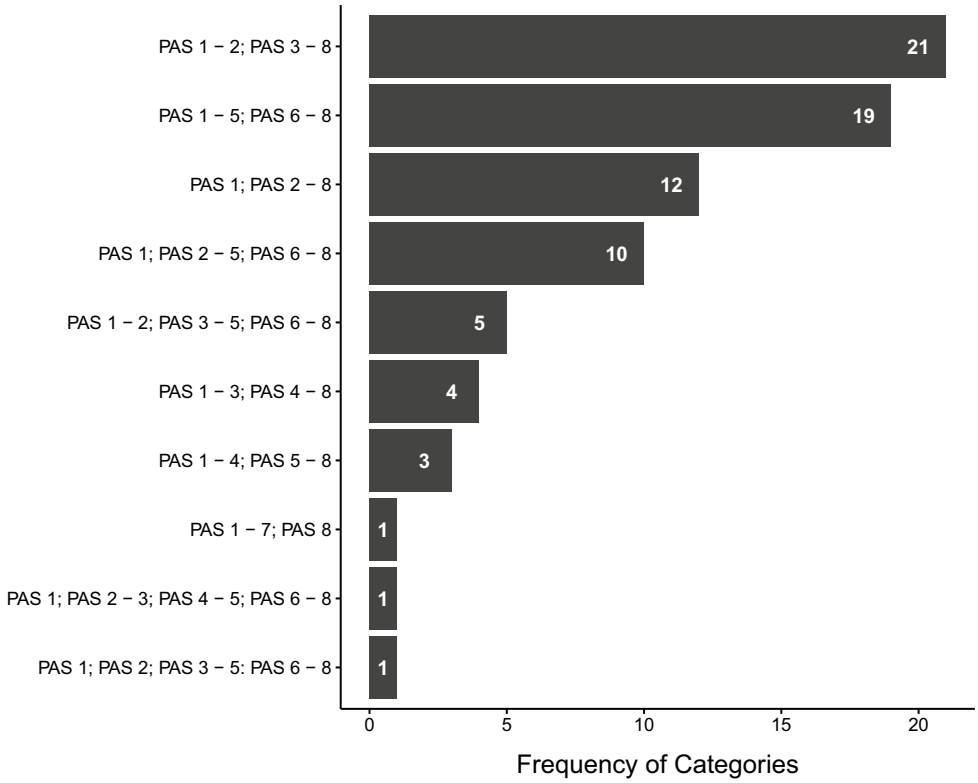

Fig. 4 Penetration-aspiration scale categories

Table 2 Categorization methods across studies

Categorization method	Frequency (%)	Studies
1–2 vs 3–8	21 (27%)	[53, 71, 73, 77, 89, 94, 98, 102, 104, 114–116, 118, 123–125, 131–133, 135, 141]
1–5 vs 6–8	19 (25%)	[30, 34, 39, 88, 90, 95, 103, 109–112, 119, 120, 122, 123, 125, 136, 143, 145]
1 vs 2–8	12 (16%)	[15, 93, 100, 105, 106, 108, 122, 134, 137–139, 142]
1 vs 2–5 vs 6–8	10 (13%)	[17, 18, 50, 96, 99, 107, 113, 117, 126, 128]
1–2 vs 3–5 vs 6–8	5 (7%)	[79, 91, 121, 140, 146]
1–3 vs 4–8	4 (5%)	[92, 101, 127, 137]
1–4 vs 5–8	3 (4%)	[97, 129, 144]
1–7 vs 8	1 (1%)	[125]
1 vs 2–3 vs 4–5 vs 6–8	1 (1%)	[110]
1 vs 2 vs 3–5 vs 6–8	1 (1%)	[130]

within an individual. Thus, methods for aggregating, summarizing, or simplifying PAS results across bolus types have the potential to affect a study's results. Analysis at the level of the bolus allows for more detailed and nuanced interpretation of findings and encourages transparency and generalizability. Studies reported several methods of aggregating or summarizing within-person PAS scores, commonly selecting the worst PAS score across boluses for analysis [30, 51, 71, 73, 96, 102, 132, 155, 156]. The rationale for the order of bolus administration was often based on patient safety concerns (i.e., smaller volumes and thicker consistencies administered first), such that the protocol may be prematurely terminated if needed. This pattern of bolus presentation presents a methodological challenge in that participants may not receive all bolus types. Participants with severe dysphagia might not receive thinner, more challenging boluses during protocol deviations. In these scenarios, we found that studies reported either using the PAS score from the most challenging bolus administered [175] or entered a PAS score of 8 for missing data [180]. While we acknowledge the necessity for making a methodological decision in these cases, neither solution truly resolves the issue of between-subject comparison. The latter method makes assumptions about a patient's sensory response to aspiration, which is concerning in light

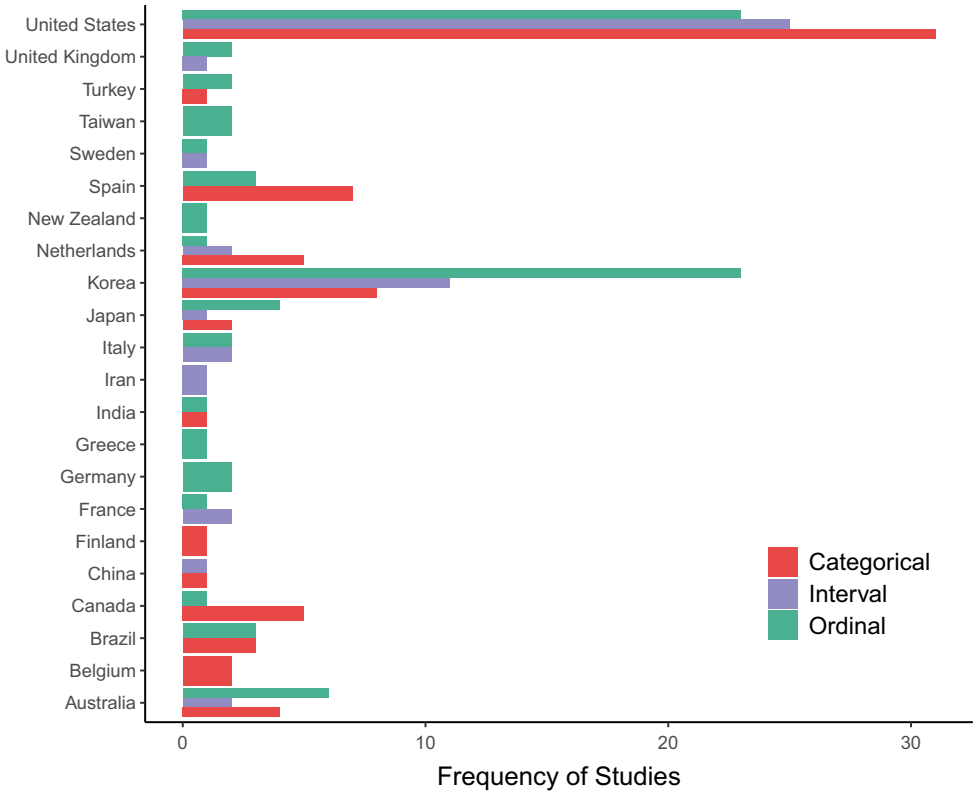

Fig. 5 Statistical analysis of the penetration-aspiration scale by country

of recent research suggesting that a cough response (e.g., PAS 7) is more common with thin compared to thick bolus consistencies [193]. Though not included in this review, studies have also used cumulative PAS scores across boluses for analysis [195, 196], though the clinical significance of these scores is unclear since the scale is not traditionally utilized in this manner.

Reporting of power analyses and reliability was uncommon across studies. Power analyses are an important aspect of experimental design in order to ensure an adequate sample size to detect statistical effects with high probability [3]. Inter- and intra-rater reliability are necessary to ensure that the scale is used in a valid and reproducible manner, and that raters are sufficiently trained in using the scale. Though there are few studies systematically examining reliability of the penetration-aspiration scale with different levels of training [5], several studies in this review reported high levels of agreement [46, 49, 78, 80, 130, 165, 182, 187]. A number of studies reported that excellent reliability had been previously documented but did not explicitly assess reliability in their own study [26, 28, 29, 50, 105, 107, 176]. Evidence of a measure's utility and reliability in prior research is important, but arguably cannot serve as a replacement for establishing reliability by the researchers reporting its use. Sufficient rater training and reporting of both inter- and intra-rater reliability is integral to establishing the validity of one's findings.

Much of the discrepancy in research using the PAS as an outcome measure may be related to inherent limitations and considerations that pose particular challenges. The PAS was not designed to capture the amount aspirated, the frequency of airway invasion events, or underlying mechanisms contributing to these events. Integration of these parameters with PAS scores is essential when assessing swallowing function. The number of trials of each bolus presented can affect PAS scores since patients may not consistently aspirate across repeated presentations of the same bolus [197, 198]. This is likely due to variability in both temporal and kinematic swallowing mechanics [199–201], which can affect airway invasion across multiple bolus trials [27]. Post-swallow residue may also be a factor in variable trial-to-trial PAS scores. Sub-swallow analyses have been used to better quantify these variations [46, 133, 202]. Alternatives have been proposed to reconcile some of these limitations, such as the dynamic imaging grade of swallowing toxicity (DIGEST) [203], which is an ordinal scale used to capture both swallowing safety and efficiency. The scale has been validated with excellent inter- and intra-rater reliability, and has been applied to head and neck cancer [204–207] and neurogenic [135, 175] populations. Steele and Grace-Martin [2] have also proposed a four-level categorical reorganization, which has yet to undergo validation. The aforementioned scales inherently measure different constructs (e.g., both efficiency and airway invasion are captured in the

Table 3 Reliability and power analyses across studies

Statistical use	Inter-rater reliability				Intra-rater reliability				Power analysis			
	Reported		Not reported		Reported		Not reported		Reported		Not reported	
	n	Studies	*n*	Studies	*n*	Studies	*n*	Studies	*n*	Studies	*n*	Studies
Ordinal	16	[9, 10, 15, 19, 20, 25, 39, 46, 47, 49, 64, 65, 67, 75, 78, 80]	63	[11–14, 16–18, 21–24, 26–38, 40–45, 48, 50–63, 66, 68–74, 76, 77, 79, 81–87]	10	[10, 19, 20, 25, 31, 36, 49, 67, 75, 80]	69	[9, 11–18, 21–24, 26–30, 32–35, 37–48, 50–66, 68–74, 76–79, 81–87].	8	[12, 18, 20, 22, 37, 39, 42, 78]	71	[9–11, 13–17, 19, 21, 23–36, 38, 40, 41, 43–77, 79–87]
Categorical	18	[15, 39, 91, 104, 115, 118, 122, 125, 129, 130, 132–134, 137–140, 142]	53	[17, 18, 30, 34, 50, 53, 71, 73, 77, 79, 88–90, 92–103, 105–114, 116, 117, 119–121, 123, 124, 126–128, 131, 135, 136, 141, 143–146]	9	[110, 115, 118, 122, 125, 130, 137–139]	62	[15, 17, 18, 30, 34, 39, 50, 53, 71, 73, 77, 79, 88–109, 111–114, 116, 117, 119–121, 123, 124, 126–129, 131–136, 140–146]	6	[18, 97, 115, 126, 134, 146]	65	[15, 17, 30, 34, 39, 50, 53, 71, 73, 77, 79, 88–96, 98–114, 116–125, 127–133, 135–145].
Interval	16	[125, 150, 152, 157, 159, 165, 168–170, 172, 177, 182, 185–188]	33	[117, 128, 145, 147–149, 151, 153–156, 158, 160–164, 166, 167, 171, 173–176, 178–181, 183, 184, 189–191]	11	[125, 151, 152, 157, 165, 170, 172, 177, 185, 186, 188]	38	[117, 128, 145, 147–150, 153–156, 158–164, 166–169, 171, 173–176, 178–184, 187, 189–191]	3	[149, 174, 187]	46	[117, 125, 128, 145, 147, 148, 150–173, 175–186, 188–191].

Studies that used multiple statistical analyses for the PAS are listed in their respective statistical groups; thus, the frequency will not reflect the total number of studies reported

DIGEST scale) and therefore are not replacements for the PAS. Instead, they should be viewed as supplements to further characterize swallowing function.

We acknowledge several limitations of this systematic review. Our search strategy ensured that all articles reviewed cited the original PAS article by Rosenbek et al. [1]; however, this strategy may have overlooked studies that used the PAS but did not meet this criterion. Furthermore, these results are not generalizable to studies using flexible endoscopic evaluations of swallowing (FEES), as these studies were excluded from the current review. Though reliability of the PAS has been demonstrated with FEES [208, 209], the scale was originally designed for interpretation during videofluoroscopy. Secondly, we recognize that it is difficult to definitively determine the statistical properties of the scale. Thus, we used the statistical test performed with the PAS as our best estimate of the scale's statistical properties, as well as the authors' reporting practices of the PAS within the results (i.e., mean or median). We believe that this methodology accurately reflects both the statistical analysis and the author's conceptualization of the scale. Finally, additional studies may have been overlooked based on our exclusion of non-English articles. This may have skewed our geographic data towards over-representation of English-speaking countries.

Conclusion

This review of the literature confirms the existence of discrepancies in the statistical treatment and reporting practices of the PAS. We found that studies to date have predominantly analyzed the PAS as either a categorical or ordinal outcome measure, though categorization appears to be increasingly gaining popularity in recent years. These discrepancies underscore the importance of early statistical consultation in study design and a thorough understanding of assumptions underlying statistical analyses. Proper training and transparent methodological reporting practices are required to ensure sufficient reliability and confidently compare results across studies. Furthermore, the approach to handling this scale dictates the statistical tests used, potentially affecting results and interpretations. Consistent application of statistically sound approaches with the PAS is vital for standardization across deglutition research, as well as accurately and responsibly translating findings to clinical practice. Future research examining the statistical properties, analysis, and clinical application of the PAS and other commonly used scales in deglutition research is warranted.

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Data Availability Data are available on the Open Science Framework at the following url: https://osf.io/5m2r7/

Compliance with Ethical Standards

Conflict of interest All authors declare that they have no conflicts of interest.

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