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Letter

Clinical breakthroughs or research oversights? The imperative of integrating modalities to differentiate signal from noise

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Keywords
Multimodal; digital phenotyping; psychotherapy research; heart rate variability; biofeedback.

Advances in technology have revolutionised our ability to collect continuous multimodal data during treatment and capture real-time information across domains.[1] This wealth of data offers unprecedented opportunities to deepen our understanding of therapeutic processes. However, it also introduces a pressing challenge: how do we distinguish clinically meaningful signals from irrelevant noise? Critically, what might initially seem like 'noise', such as a sudden high-pitched tone reflecting an almost-crying expression, may hold valuable insights into the therapeutic process. Navigating this question lies at the intersection of research and clinical practice, where conflicting priorities often pose significant challenges.

The pre-processing dilemma: outliers or opportunities for therapeutic insight?

Conventional pre-processing techniques such as outlier removal or dimensionality reduction are often essential for mitigating issues associated with the 'curse of dimensionality',[2] including data sparsity and overfitting. However, critical tension arises during the pre-processing phase of clinical data analysis, where decisions about retaining or discarding data points can profoundly affect the interpretation of findings. In clinical practice, deviations from a patient's 'norm' – frequently labelled as 'outliers' – often serve as focal points for therapeutic attention. These deviations must be understood in the context of the patient's trait-like individual-specific dynamic patterns,[3] which capture their unique baseline patterns of physiological, behavioural and emotional responses before treatment.[1] For example, a sudden spike in physiological arousal during a session might signify an emotionally charged moment critical to the patient's progress.[4] Moreover, the capacity to exhibit a broad range of physiological or behavioural expressions can signal adaptive flexibility, whereas consistently limited variability may indicate either stability or maladaptive rigidity, as observed in measures such as heart rate variability (HRV) or vocal pitch range.[5,6] However, in research, these same deviations are often excluded during pre-processing to create cleaner data-sets,[7] risking loss of valuable clinical insights. Understanding these deviations as departures from the patient's trait-like dynamic can reframe them as indicators of potential therapeutic significance rather than statistical anomalies.[1] This dilemma underscores the need for a nuanced approach to data handling that balances research rigour with clinical relevance.

A clinical example: Sarah's journey through trauma-focused therapy

Consider Sarah,[a] a 32-year-old client undergoing trauma-focused therapy, whose sessions were recorded with continuous HRV monitoring and acoustic analysis. Before treatment, Sarah's trait-like individual-specific dynamic was characterised by avoidance and emotional suppression, reflected in muted HRV fluctuations and a reluctance to engage with traumatic material. During session 7, as she confronted a deeply suppressed childhood memory, her HRV data showed several brief but pronounced drops (Fig. 1). Clinically, these moments indicated a significant shift: Sarah's first meaningful engagement with traumatic material, suggesting emotional activation and potential progress in therapy. This physiological response marked a clear departure from her trait-like avoidance pattern, providing evidence of therapeutic engagement.

Under conventional research protocols, these deviations were labelled as 'artifacts' and excluded during pre-processing, distorting the HRV data-set to misleadingly reflect emotional stability while erasing potential therapeutic breakthroughs. Recognising Sarah's pre-treatment dynamic helped clinicians to interpret these deviations as meaningful shifts rather than noise, offering critical insights into her emotional processing. Had these physiological changes been analysed alongside behavioural shifts, they could have provided crucial input for tailoring interventions to deepen trauma processing.

The multimodal advantage: enhancing clinical signal clarity through modal synergy

This dilemma – whether to interpret such data as meaningful or dismiss it as noise – can be resolved through the integration of additional modalities.[8] For example, acoustic analysis of Sarah's session offered critical context: at the precise moments when her HRV dropped, her vocal features displayed significant changes. The fundamental frequency (F_0) rose by 30%, jitter and shimmer values doubled, her speech rate slowed and her voice intensity fluctuated. These well-established markers of heightened emotional arousal corroborated the clinical importance of the HRV shifts, transforming what might have been dismissed as noise into clear indicators of emotional processing.

Integrating HRV and acoustic data allowed apparent noise to be recontextualised as a coordinated physiological–emotional response. Validated by state-like deviations from Sarah's trait-like dynamic and multimodal convergence, these moments marked her first engagement with repressed trauma, enabling tailored processing. Real-time measurements clarified their context – timing, duration and Sarah's awareness. In later sessions, similar

a. Sarah's case is an anonymised synthesis derived from multiple cases within a pool of 250 patients treated in our psychotherapy laboratory, all of whom provided informed consent; for privacy reasons, she does not represent a real individual.

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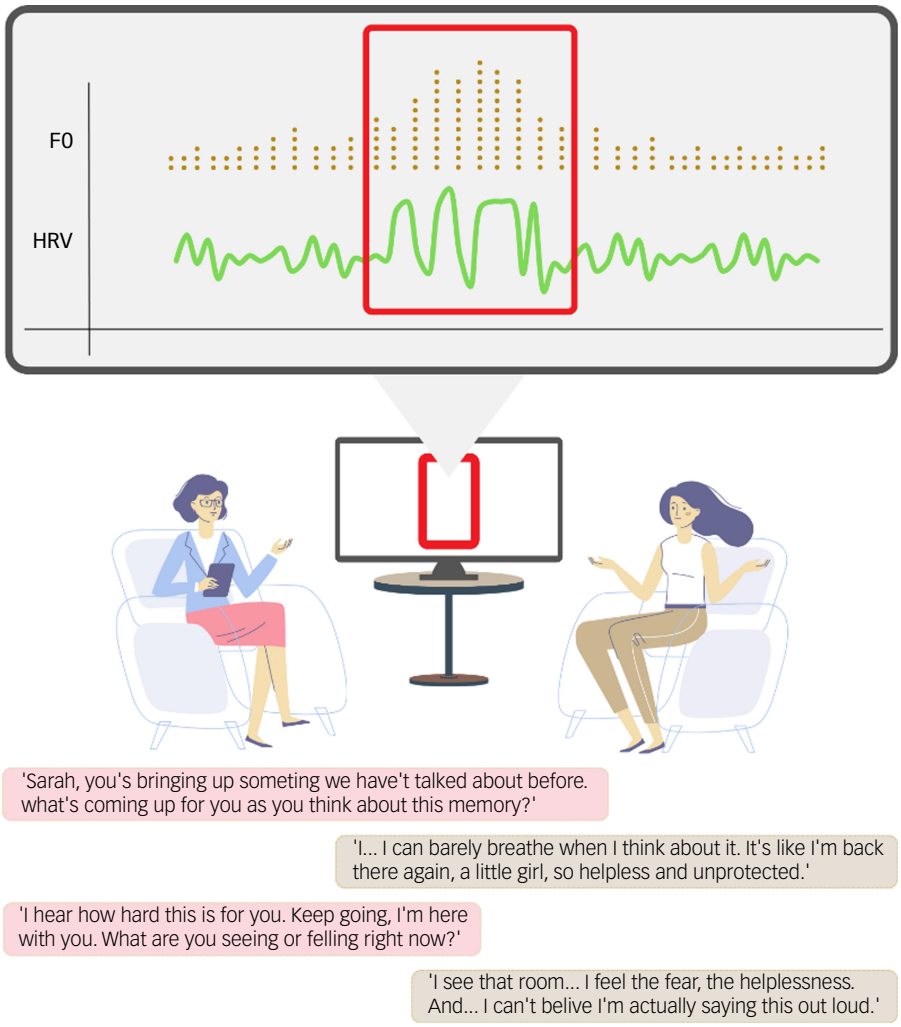

Fig. 1 Multimodal insights from Sarah's session 7: acoustic (fundamental frequency; F_0) and physiological (heart rate variability; HRV) shifts during the emotional breakthrough.

HRV drops with acoustic shifts consistently preceded breakthroughs, providing reliable progress indicators and actionable insights for personalised interventions.

Building on the multimodal advantage, one potential strategy for clinically sensitive pre-processing is to align timestamped multimodal streams (e.g. HRV, vocal acoustics, linguistic content) and flag as potentially meaningful any data segment in which an outlier in one modality is temporally mirrored by a deviation in at least one other clinically related modality. For example, if a brief but sharp drop in HRV occurs simultaneously with reduced pitch variability and prosodic flattening in voice data, the likelihood that this reflects a meaningful emotional shift rather than physiological or measurement noise increases substantially. Such an approach allows researchers to retain outliers that are supported across channels, balancing statistical rigour with clinical nuance.

Towards clinically informed multimodal data processing

Standardised pre-processing guidelines are essential for maintaining consistency across studies. However, they risk inadvertently discarding clinically meaningful insights. Effective data cleaning and preparation require thoughtful judgement that incorporates both statistical rigour and clinical expertise. Transparency in documenting these decisions is critical for fostering reproducibility, reliability and trust in empirical findings. By creating synergy among the patient's trait-like dynamic patterns, clinical expertise and insights offered by multimodal data, researchers can refine pre-processing protocols to align rigorous methodologies with practical applications, preserving meaningful signals and effectively bridging the gap between research and clinical practice.

Rethinking 'outliers' in multimodal data: enabling real-time clinical insights

This Letter advocates for a paradigm shift in how multimodal data are approached in psychological research and practice. Preserving outliers during model training may enhance clinical usability by retaining signals of meaningful change, particularly when such deviations reflect therapeutically relevant departures from an individual's baseline. Integration of clinical expertise into data processing and prioritisation of transparency are essential to distinguish meaningful signals from noise. Leveraging the multimodal advantage is paramount. Noise, such as a door closing, often occurs in isolation within a single modality, whereas pivotal clinical moments such as emotional arousal are likely to manifest

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across multiple modalities, for instance, voice quality, text content, movement patterns, facial expressions and physiological markers. By harnessing the convergence of signals across modalities, researchers and clinicians can uncover richer, more accurate insights into therapeutic processes.

An additional advantage of the proposed multimodal approach is its potential to enable real-time feedback systems. By using multimodal data collection to automatically differentiate clinically meaningful signals from noise, this framework can support the development of feedback mechanisms that alert therapists to critical processes occurring in the patient or the dyad during the session.[9] This real-time capability is crucial for fostering timely, personalised and effective interventions, enhancing the integration of research insights into clinical practice, and advancing the precision and impact of therapeutic care.

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S.Z.-M. led the conceptualisation of the manuscript, and was responsible for the overall structure and theoretical framework, as well as the writing of the manuscript. A.T., A.N., M.M. and Y.O. contributed to various aspects of the conceptualization and writing process. They provided feedback, refined the arguments, and ensured clarity and coherence throughout the writing process.

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Declaration of interest

None.

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