ChatGPT

Respiratory Entrainment & HRV Biofeedback – Key Literature (Paced Breathing ~0.1 Hz)

1. **Lehrer et al. (2020)** – *Heart Rate Variability Biofeedback Improves Emotional and Physical Health and Performance: A Systematic Review and Meta Analysis.* Applied Psychophysiology and Biofeedback, 45(3), 109–129. DOI: 10.1007/s10484-020-09466-z. **Findings:** This comprehensive meta-analysis of 58 RCTs found that HRV biofeedback produces a **small-to-moderate overall effect** on diverse outcomes, comparable in magnitude to other established treatments [1]. Notably, the **largest benefits** were seen for anxiety, depression, anger, and athletic performance, whereas effects on PTSD, sleep, and quality of life were smaller [2]. Outcomes did **not depend strongly on number of sessions** or whether measures were disorder-specific; significant gains appeared against both active and inactive controls [3]. **Relevance:** Demonstrates broad efficacy of paced-breathing HRV training across mental and physical domains, validating it as a versatile intervention for autonomic regulation. It also suggests HRV biofeedback's impact is on par with standard treatments, supporting its inclusion in self-regulation toolkits. **Limitations:** The analysis spans varied populations and endpoints with relatively few studies per subgroup, so specific use-cases (e.g. PTSD, insomnia) have limited data. It emphasizes the need for more targeted trials even though overall effects are positive. (Level: **Meta-analysis**) [2]

2. **Shao et al. (2024)** – *The Effect of Slow-Paced Breathing on Cardiovascular and Emotion Functions: A Meta-Analysis and Systematic Review.* Mindfulness, 15(1), 1–18. DOI: 10.1007/s12671-023-02294-2. **Findings:** Pooled data from 31 studies (n=1133, healthy/nonclinical) confirmed that breathing ~6 breaths/min yields **significant acute physiological benefits**: **systolic BP** dropped (SMD ≈ –0.45), **HRV** increased (e.g. RMSSD SMD ≈ +0.37; SDNN SMD ≈ +0.77) and **heart rate** slowed slightly [4]. The effect on **negative emotion (perceived stress)** was modest (SMD ≈ –0.51) and marginally significant [5]. Limited follow-up data hinted that blood-pressure reductions might persist up to 3 months in pre-hypertensives [6]. **Relevance:** Quantifies the magnitude of "resonant" slow breathing's impact on key autonomic markers in everyday populations – confirming that ~0.1 Hz breathing acutely **boosts vagal tone (HRV)** and slightly **alleviates stress** [7] [8]. This evidence underpins practical breathing protocols for stress reduction and cardiovascular health (e.g. daily 5–15 min of 6 BPM breathing). **Why it matters:** For "sci-magic" data extraction, it provides benchmark effect sizes (e.g. ~10–77% improvements in HRV indices) that can be expected from paced-breathing exercises, aiding in evidence-based program design. **Known Limitations:** Most included studies examined **immediate** effects; evidence for long-term training benefits is still sparse [9]. The meta-analysis is restricted to healthy people – effects in clinical groups or chronic practice scenarios may differ. Heterogeneity in protocols and outcomes (I^2 ~45%) suggests results should be generalized with caution. (Level: **Meta-analysis**) [4] [8]

3. **Goessl et al. (2017)** – *The effect of heart rate variability biofeedback training on stress and anxiety: a meta-analysis.* Psychological Medicine, 47(15), 2578–2586. DOI: 10.1017/S0033291717001003. **Findings:** This meta-analysis (24 studies, n=484) found **large anxiety/stress reductions** with HRV biofeedback. Pooled effect sizes were **Hedges' g ≈ 0.81** pre–post and **g ≈ 0.83** compared to controls

[10]. Effects were **consistent across subgroups** – no significant moderation by number of sessions, study year, presence of clinical anxiety, etc. [10]. **Relevance:** Establishes HRV biofeedback as a potent intervention for stress and anxiety relief. The robust ~0.8 SD symptom improvement underscores that even **short-term HRV biofeedback** can markedly reduce stress, making it attractive for wearable/app-based self-help [11]. This supports the "breath coherence" approach as a practical therapy for emotional health. **Why it matters:** For automated extractors, it highlights a high-impact outcome domain – psychological stress – where paced breathing has proven efficacy, and it signals that **effective protocols need not be lengthy** (since outcomes didn't depend on session count). **Known Limitations:** Many included studies had small samples or weaker controls; objective physiological changes were not always reported alongside symptom relief. The authors note the field's need for more rigorously controlled trials despite the encouraging results [12]. (Level: **Meta-analysis**) [10]

4. **Marzorati et al. (2021)** – *A meta-analysis on heart rate variability biofeedback and depressive symptoms.* Scientific Reports, 11, 13641. DOI: 10.1038/s41598-021-93038-y. **Findings:** In 14 RCTs (n=794, mixed medical/psych populations), HRV biofeedback led to a **moderate improvement in depression** (pooled Hedges' g = 0.38, $p < .001$) [13]. There was **significant heterogeneity (I^2 ~45%)**; meta-regressions indicated larger effects in **more recent studies** and when certain depression scales were used [14] [15]. Overall, HRV-BF was effective in alleviating depressive symptoms across varied conditions and comparable to many standard treatments in effect size [15]. **Relevance:** Demonstrates that vagal-tone training via breath can positively affect mood regulation. This solidifies paced breathing as a *"mind-body" adjunct for depression*, likely by enhancing resilience and parasympathetic function associated with emotional control [16]. **Why it matters:** Provides an evidence base for extracting **mental health outcomes** linked to breath coherence techniques – indicating a quantifiable (~0.4 SD) symptom relief that "sci-magic" applications can expect in mood disorder contexts. **Known Limitations:** Variability in patient populations (some studies in cardiac patients, others in major depression, etc.) and control conditions contributes to heterogeneity. Some risk of bias and small-study effects exist (though no significant publication bias was detected) [17] [18]. The analysis focuses on short-term symptom changes; long-term depression relapse prevention via HRV-BF remains to be studied. (Level: **Meta-analysis**) [13] [14]

5. **Zaccaro et al. (2018)** – *How Breath-Control Can Change Your Life: A Systematic Review on Psycho-Physiological Correlates of Slow Breathing.* Frontiers in Human Neuroscience, 12, 353. DOI: 10.3389/fnhum.2018.00353. **Findings:** This systematic review (15 studies) showed that **voluntarily slowing respiratory rate (<10 breaths/min)** yields convergent autonomic and central effects. Across studies, **slow breathing increased HRV and respiratory sinus arrhythmia** (parasympathetic indicators) and shifted CNS activity – for example, **EEG alpha power rose and theta power fell**, consistent with a relaxed yet alert state [19]. Participants practicing slow or meditative breathing reported **greater comfort, calmness, vigor, and lower anxiety/anger** [20]. An fMRI study even found enhanced activation in brain areas involved in emotion regulation (eg. pons, hypothalamus) during slow breathing [21]. **Relevance:** Elucidates the *mechanistic underpinnings* of breath-focused practices: linking **increased vagal tone** and **neuronal oscillatory changes** to psychological well-being [22]. It supports ancient practices (pranayama, etc.) with scientific evidence that breath control can drive adaptability in both autonomic and central nervous system function. **Why it matters:** From an extractor's viewpoint, this review provides a conceptual map of outcomes to look for – e.g. HRV ↑, specific EEG changes, improved mood – when analyzing breath entrainment interventions, bridging physiological and psychological domains. **Known Limitations:** Only a small number of studies met

strict criteria, and they were heterogeneous (different breathing techniques, durations, and outcome measures). Most were short-term experiments in healthy adults [23]. Thus, while the observed effects are promising, more standardized research is needed to confirm causal pathways (including the review's interesting hypotheses about interoceptive control vs. nasal mechanoreceptor pathways for breath effects [22]). (Level: **Systematic Review**) [19] [22]

6. **Bernardi et al. (2001)** – *Effect of rosary prayer and yoga mantras on autonomic cardiovascular rhythms: a comparative study.* British Medical Journal, 323(7327), 1446–1449. **Findings:** This seminal study found that **reciting the Ave Maria prayer or a yoga mantra** (in Latin and Sanskrit respectively) automatically slowed breathing to ~6 breaths/min, producing a **"coherent" cardio-respiratory rhythm**. Both prayer and mantra evoked **striking 0.1 Hz oscillations** in heart rate and blood pressure, accompanied by a **significant increase in baroreflex sensitivity** (from ~9.5 to 11.5 ms/mmHg, $p<0.05$) [24]. In short, the simple act of rhythmic prayer chanting induced a strong synchrony between breathing and cardiovascular oscillations, **enhancing vagal baroreflex function and HRV** [25]. **Relevance:** This study bridges *cultural/spiritual practices* with physiology, showing that traditional breath-paced rituals naturally achieve the 0.1 Hz resonance known to optimize HRV. It provides a proof-of-concept that "ritual breath coherence" (e.g. saying the rosary) can confer measurable autonomic benefits, effectively validating folk wisdom with science. **Why it matters:** For integrative applications, it highlights that **breathing at ~6/min** is a unifying element across cultures (prayer, mantra) that yields HRV/baroreflex improvements – a key insight for extracting or designing interventions that tap into existing spiritual practices. **Known Limitations:** The sample (23 healthy adults) was small, and the setting acute; we don't know how long such autonomic improvements persist or how they translate to clinical outcomes. Nonetheless, it points to a low-cost, accessible means of achieving HRV resonance, albeit requiring further research to generalize to different populations and long-term practice. (Level: **Controlled Experimental Study**) [24] [25]

7. **Vaschillo et al. (2006)** – *Characteristics of resonance in heart rate variability stimulated by biofeedback.* Applied Psychophysiology and Biofeedback, 31(2), 129–142. DOI: 10.1007/s10484-006-9009-3. **Findings:** This foundational work by Vaschillo's team elaborated how **breathing at the individual's cardiovascular "resonant frequency" (~0.1 Hz)** via HRV biofeedback leads to large-amplitude oscillations in heart rate and blood pressure. Breathing at resonance causes a **4–10× increase in HRV amplitude** compared to baseline and significantly **boosts baroreflex gain** (the responsiveness of heart rate to blood pressure changes) [26] [27]. The authors also showed that each person's resonant breathing rate is fairly **fixed and reproducible** – related inversely to body size (taller individuals had slightly lower resonance frequencies) and **remains stable across ~10 training sessions** [28]. **Relevance:** This study established the **biophysical basis** for HRV biofeedback: identifying the resonance mechanism by which paced breathing maximizes vagal-cardiac influence and reflex efficiency. It essentially provided the "user manual" for resonance frequency breathing, which has guided protocol development (e.g. the standard 6 breaths/min heuristic comes from such work). **Why it matters:** From a data perspective, it underscores the importance of the ~0.1 Hz parameter – extractors should note whether an intervention achieves or targets this specific frequency, as it's key to efficacy (maximizing RSA and baroreflex effects). It also informs that **individual calibration** might be needed, since optimal rate can vary person to person. **Known Limitations:** These early studies were done in healthy individuals (and some asthma patients) under controlled settings; while they measured physiological improvements (e.g. peak expiratory flow in asthma, baroreflex gain), the translation to clinical symptom relief was only hypothesized. Additionally, determining each person's exact resonance requires initial assessment; some later

studies simply use ~6 BPM for convenience, which may be slightly suboptimal for certain individuals. (Level: **Experimental Physiology Study**) [26] [28]

8. **Gevirtz (2013)** – *The Promise of Heart Rate Variability Biofeedback: Evidence-Based Applications.* Biofeedback, 41(3), 110–120. DOI: 10.5298/1081-5937-41.3.01. **Findings:** In this narrative review, Gevirtz surveyed the landscape of HRV biofeedback research up to 2013, covering applications from **asthma, COPD, IBS, fibromyalgia, hypertension, chronic pain, anxiety, depression, PTSD, insomnia, to athletic performance** [29]. While controlled evidence varied by condition (some had only pilot studies), the **overall picture was very promising** – multiple trials indicated symptom improvements, often attributed to rebalancing autonomic function. Mechanistically, the review explains how HRV-BF causes heart rate oscillations to become **large in amplitude and sinusoidal**; even novices can achieve a big increase in RSA within seconds by breathing at their resonance [30]. It posits that such high-amplitude HRV might restore autonomic homeostasis and engage vagal afferent pathways (even suggesting anti-inflammatory effects via the cholinergic pathway). **Relevance:** This paper summarizes *why HRV biofeedback works* and its breadth of uses. It's essentially a **conceptual and evidence primer** that influenced many subsequent clinical studies. It underscores that a wide array of psychosomatic conditions share an autonomic dysregulation component that HRV training can ameliorate. **Why it matters:** For extraction purposes, Gevirtz's review highlights key outcome domains and mechanisms to watch for (e.g. improved autonomic balance, reduced inflammation, etc.) across different disorders. It also provides historical context – noting that HRV-BF reliably causes acute physiological changes (huge RSA boosts) in nearly everyone [31], which is the basis for its therapeutic potential. **Known Limitations:** As a broad review in a biofeedback trade journal, it is not a systematic meta-analysis; some claims were forward-looking (hypothesizing mechanisms that required more empirical confirmation). By 2013, controlled trials were still sparse in some areas, so the review's optimism needed to be tempered by the fact that long-term or large-scale evidence was limited for certain conditions. (Level: **Expert Review**) [29] [30]

9. **Firth et al. (2022)** – *The Effect of Heart Rate Variability Biofeedback Training on Vagal Tone in Athletically Talented Secondary School Students.* Sports (Basel), 10(10), 146. DOI: 10.3390/sports10100146. **Findings:** In this randomized study, 30 adolescent athletes were assigned to 6 weeks of HRV biofeedback (with or without added mental skills training) vs control. **Result: no significant differences** were found in any vagal HRV metrics (e.g. high-frequency HRV, RMSSD) **pre- vs post-training** [32]. Even when combining all biofeedback trainees, **vagally-mediated HRV did not reliably increase**. The authors note this aligns with other reports: many HRV-BF interventions show **clinical or performance benefits without corresponding resting HRV increases** [33]. In fact, a review of the field found **few studies demonstrate sustained vagal tone elevation** between sessions – improvements in symptoms often occur via other pathways (e.g. baroreflex or central nervous system changes) rather than a straightforward rise in baseline HF-HRV [34] [33]. **Relevance:** This study offers a cautionary perspective – simply doing paced breathing exercises does not guarantee an upward shift in resting "vagal tone" in young, healthy individuals. It urges a more nuanced view of mechanism: **benefits of HRV biofeedback might come from acute flexibility and baroreflex engagement during practice** or psychological factors, rather than permanently raised HRV. **Why it matters:** For those extracting data, it highlights an important **limitation/metric**: one should track not just outcomes but also whether the intended physiological target (like increased HF-HRV) was achieved. It reminds us that **lack of change in HRV** does not equal lack of benefit – and vice versa – so interpretation of HRV metrics in studies must be careful [35]. **Known Limitations:** The study's sample was specific (high-performing teens) and relatively small, possibly underpowered to

detect subtle HRV changes. Training dose was moderate (12 sessions); maybe longer or more intensive practice is needed to alter resting vagal activity. Nonetheless, the null finding is valuable in tempering "one-size-fits-all" assumptions and suggests investigating other indicators (e.g. baroreflex sensitivity, stress hormones, cognitive changes) when evaluating HRV-BF effects. (Level: **Randomized Controlled Trial**) [32] [33]

10. **Blum et al. (2019)** – *Heart Rate Variability Biofeedback Based on Slow-Paced Breathing With Immersive Virtual Reality Nature Scenery.* Frontiers in Psychology, 10, 2172. DOI: 10.3389/fpsyg.2019.02172. **Findings:** This RCT compared a **standard HRV biofeedback session** (paced breathing at ~6 BPM with on-screen cues) to the **same protocol delivered in VR** (immersive 3D nature environment), in 60 healthy employees. Both groups achieved **equivalent biofeedback performance** – i.e. similar increases in cardiac coherence/HRV and vagal indexes during the session [36]. However, the **VR group reported additional benefits**: during a post-training stressor, they had **lower perceived stress, better attentional focus, and less mind-wandering** than the non-VR group [37]. VR participants also rated the experience as more engaging and relaxing. **Relevance:** This study suggests that while the core physiological effect of paced breathing doesn't require VR, the use of **immersive technology can enhance the psychological outcomes and user experience**. It points toward HRV biofeedback's integration with modern **XR (extended reality)** or gaming techniques to potentially improve adherence and enjoyment. **Why it matters:** For tech-oriented "sci-magic" implementations, this provides evidence that **delivery medium matters** – a calming VR environment can amplify stress-reduction and present-moment awareness beyond what a generic app might do, without sacrificing physiological efficacy. It highlights a path for innovating biofeedback training tools (e.g. VR, AR apps) to maximize benefit. **Known Limitations:** This was a **single-session** study; it's unclear if VR's added effects persist with repeated use or are mainly novelty. Also, participants were young adults in a lab – results might differ in clinical populations or if motion sickness/tech issues arise. Cost and accessibility of VR may be concerns. Nevertheless, it demonstrates feasibility and an initial boost in outcomes when merging paced-breathing with immersive media. (Level: **Randomized Controlled Trial**) [37]

11. **Woo & Kim (2025)** – *Effects of slow-paced breathing and humming breathing on heart rate variability and affect: a pilot investigation.* Physiology & Behavior, 299, 114972. DOI: 10.1016/j.physbeh.2025.114972. **Findings:** This crossover pilot (n=16) tested **5 min of app-guided slow paced breathing (SPB)** at 6 BPM versus **5 min of humming pranayama** (a yoga breathing technique where one hums on exhale). Both interventions, compared to rest, produced **significant HRV increases** – higher SDNN, total power, and low-frequency (LF) HRV – and **greater self-reported relaxation** [38]. Importantly, **humming breathing was just as effective as paced breathing** on all measures; no significant differences emerged between the two techniques [39] [40]. Participants found both methods easy, though humming requires no external device or pacer. **Relevance:** This study suggests a **culturally rooted, technology-free method (humming/chant breathing)** can achieve physiological coherence comparable to structured breath training. The vibratory exhalation of humming likely engages vagal pathways (via the larynx and sinuses) similarly to how paced deep breathing does. **Why it matters:** It highlights an alternative protocol that extractors might encounter – **tonal breathing or chanting** – as a legitimate HRV-enhancing practice. For practical applications, it means users could get benefits of HRV biofeedback even without any app or visual feedback, simply by following a rhythmic hummed chant (which might improve adherence for some). **Known Limitations:** As a small pilot, the findings are preliminary. Only short-term, immediate effects were measured; we don't know if one technique might surpass the other with longer training

or under stress conditions. Also, this was in healthy adults – efficacy and user preference might differ in anxious or less tech-savvy populations. Nonetheless, it provides a proof-of-concept that diverse breathing styles can converge on the same beneficial endpoints. (Level: **Experimental Pilot Study**) [39] [38]

12. **Ribeiro et al. (2023)** – *Assessing effectiveness of heart rate variability biofeedback to mitigate mental health symptoms: a pilot study.* Frontiers in Physiology, 14, 1147260. DOI: 10.3389/fphys.2023.1147260. **Findings:** In this open-label trial, 21 frontline healthcare workers (HCWs) underwent a **5-week HRV biofeedback program (1 session/week)** during the COVID-19 pandemic. **Before vs. after**, participants showed **lower self-reported stress, anxiety, and depression symptoms**, along with physiological changes indicative of improved autonomic balance [41] . Specifically, their **resting respiratory rate decreased**, and HRV measures like SDNN and LF norm **increased significantly** post-training [42] [43] . An objective "stress index" derived from wearable sensors also suggested reduced chronic stress after the intervention [44] . **Relevance:** This study demonstrates that even a **brief, low-dose HRV biofeedback regimen** can yield measurable mental health benefits and autonomic improvements in a high-stress group (HCWs). It's particularly relevant as it was done **remotely/in the field**, showing potential for telehealth or workplace stress programs using wearable-guided breathing sessions. **Why it matters:** It provides a real-world example of short **HRV-biofeedback protocols (around ~20 min per week for 5 weeks)** being feasible and effective – information valuable for extractors looking at pragmatic implementations. It also highlights combined **subjective and objective outcome tracking** (questionnaires + physiological monitoring), a best-practice approach for validating stress interventions. **Known Limitations:** The study lacked a control group, so improvements can't be definitively attributed to HRV-BF (placebo or Hawthorne effects possible). Sample size was small, and participants were self-selected, which may bias results. Nonetheless, the positive trends in both feelings and physiology provide a rationale for larger controlled trials and indicate that even **time-strapped professionals** can benefit from short coherence practices. (Level: **Pilot Intervention Study**) [41] [43]

13. **Lalanza et al. (2023)** – *Methods for Heart Rate Variability Biofeedback (HRVB): A Systematic Review and Guidelines.* Applied Psychophysiology and Biofeedback, 48(3), 275–297. DOI: 10.1007/s10484-023-09582-6. **Findings:** This methods review analyzed **143 studies (2000–2021)** to catalog how HRV-BF has been applied. It identified three main protocol types: **(i) "Optimal RF"** – each person breathes at their individually assessed resonance frequency (37 studies); **(ii) "Device-guided Individual RF"** – a biofeedback device algorithmically guides breathing in real-time (48 studies); **(iii) "Preset Pace"** – all participants breathe at a fixed rate (usually 6 BPM) without individualization (51 studies) [45] . There was wide variation in **training duration** (1 to >10 weeks) and session length (from ~5 min to >20 min). Alarmingly, **~65% of studies lacked sufficient detail to replicate the protocol** – omitting information like breathing duration, inhale/exhale ratio, whether nose or mouth breathing, posture, etc. [46] [47] . The authors provide a checklist of reporting guidelines to improve consistency. **Relevance:** This paper serves as a **state-of-the-art reference for HRV-BF protocol design**. It tells us that not all studies use the same breathing method – some precisely tailor to each individual's physiology, while others use a one-size-fits-all 0.1 Hz pacing. This influences how results can be interpreted and compared. **Why it matters:** For meta-analyses or automated extraction, recognizing these protocol differences is crucial – e.g., did a study use true resonance frequency assessment or just assume 6 BPM? Such details affect training effectiveness and outcomes. The finding that many reports are incomplete is a heads-up that data extraction may require going back to authors or supplementary materials. **Known Limitations:** The review focuses on methodological

reporting rather than outcomes, so it doesn't directly tell which protocol is "best" (though it implicitly suggests individualized RF might maximize efficacy). It also includes all kinds of studies (open trials, RCTs, case studies) in the tally, without quality exclusion, since the goal was to gather protocol info. The proposed guidelines, if adopted, will make future research more interpretable – a point in time for extractors to note improvements in reporting after 2023. (Level: **Systematic Review – Methods**) [45] [47]

14. **Hirten et al. (2024)** – *Remote Short Sessions of Heart Rate Variability Biofeedback Monitored With Wearable Technology: Feasibility Study.* JMIR Mental Health, 11(1), e55552. DOI: 10.2196/55552. **Findings:** This study examined a **fully remote, self-guided HRV-BF program** for New York healthcare workers. Participants (n=127) were asked to do **5-minute daily breathing sessions** (with a smartphone app) for 5 weeks, while wearing an Apple Watch to passively track HRV. **Feasibility issues emerged:** only 16.5% of participants adhered to at least half of the prescribed sessions – **compliance was very low** [48]. Consequently, **group-level psychological improvements were small and non-significant**, though there was a **numeric trend of improved stress and well-being scores** over 17 weeks [49]. In the subset who did practice regularly, wearable data hinted at **increased SDNN (24-hour HRV)** during the intervention weeks [50]. The authors conclude that the intervention as implemented was **not very feasible** due to poor engagement, but it shows *some promise* in autonomic improvement for those who were adherent [51]. **Relevance:** This study provides a reality check for digital HRV interventions: *short daily breathing exercises can be effective, but user engagement is a major hurdle* in unsupervised settings. It highlights the importance of designing for adherence (gamification, reminders, support) when deploying HRV biofeedback via apps and wearables. **Why it matters:** For any automated system analyzing such programs, it underscores that **high dropout or non-usage rates** may confound outcomes. It also illustrates how wearable HRV metrics can be used as an objective progress marker (here, circadian HRV patterns were analyzed), which is an emerging approach in remote trials. **Known Limitations:** The study's intervention relied on participants' self-motivation with minimal contact, which clearly limited engagement – a limitation of the study but also common in real-world wellness apps. The results must be interpreted with that lens: those who actually did the breathing tended to benefit, but reaching adequate compliance in a busy HCW population was difficult. This suggests future strategies (shorter but more frequent sessions, incentives, or integration into work routines) are needed. Despite these issues, the study proves the concept that large-scale *remote HRV-BF with wearable monitoring is doable*, even if improvements in design are needed to make it effective. (Level: **Prospective Feasibility Study**) [48] [51]

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