

# The Daily Experience of Subjective Tinnitus: Ecological Momentary Assessment Versus End-of-Day Diary

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**Objective:** Traditional methods of self-report assessments are susceptible to bias (i.e., memory, recall, and recency). Ecological momentary assessment (EMA) may curb these biases by repeated momentary assessment of the participant throughout the day. High costs and participant burden may, however, impede the use of EMA. End-of-day diary (EDD) provides an attractive alternative to EMA, though no direct comparison has been performed in the tinnitus field.

**Design:** Four thousand seven-hundred thirty-two data entries were collected from nine participants undergoing cognitive behavioral treatment for tinnitus. Eleven equivalent EMA and EDD items were collected for approximately 3 months. Tinnitus experience (i.e., anger, annoyance, avoidance, distraction, fear, invasiveness, pleasantness, and sadness) and well-being (i.e., anxiety, happiness, and stress) were correlated and means compared (t-tests).

**Results:** All variables presented adequate correlation ( $r > 0.68$ ) between the EMA and EDD counterparts. Small (<3.9%) significant daily mean differences between EMA and EDD were found for six variables (tinnitus anger, invasiveness, pleasantness, sadness, as well as anxiety and stress) with worse results reported in EDD.

**Conclusion:** The small significant effects found may be attributed to the large number of data points. When EMA is not possible or recommended, EDD provides a viable alternative to assess tinnitus experience daily. Further research on the underlying mechanisms of tinnitus experience and recollection is warranted.

**Key words:** Diary, Ecological momentary assessment, Outcome measure, Tinnitus.

(Ear & Hearing 2022;43:45–52)

## INTRODUCTION

The use of ecological momentary assessment (EMA) has risen with the development of technology and growing availability of smartphones. The increased use of EMA has been reflected in a variety of research fields, including suicidal ideation (e.g., Kleiman et al. 2017), substance use (e.g., Jones et al. 2019), and chronic pain (e.g., May et al. 2018), to name but a few (for a comprehensive review on EMA, we guide the interested reader to Shiffman et al. 2008). EMA aims at capturing experiences during real-life activities and situations by assessing individuals at several random times during the day.

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The advantages of these in-the-moment assessments are three-fold: (1) reduced recall bias; (2) increased ecological validity; and (3) the exploration of symptom fluctuation (Schneider & Stone 2016). Recall bias refers to any unwanted bias associated with the cognitive processes of memory reconstruction (e.g., mood, setting, and recency) and summation (i.e., average) of these experiences (Stone & Shiffman 1994; Shields et al., 2016). Reducing the time between events and assessment reduces recall bias and focuses on reaching information that can be accessed in working memory. Increased ecological validity is achieved by assessing the participant during real daily-life situations, and thus outside a setting that may unduly influence responses (e.g., hospital, clinic, and laboratory). Fluctuation patterns of experiences (e.g., stress and tinnitus annoyance) during the individual's daily life may provide insights in the relationship of those variables with specific (e.g., social) or cyclical (e.g., sleep/awake) patterns. To capture such data, EMA is deployed several times during each day, requiring participants to remain in possession of their smartphone at all times, and allow interruption of activities to respond to the assessments. Such intrusiveness has been suggested to potentially produce negative outcomes in participants. Smartphone use has been associated with increased stress, anxiety, depression (Elhai et al. 2017; Vahedi & Saiphoo 2018), and lower well-being (Horwood & Anglim 2019). While symptom fluctuation during the day may be of importance to researchers and clinicians, daily average EMA scores can provide a broader daily picture.

Similarly, to EMA, end-of-day diary (EDD) minimizes the effects of recall bias by being deployed once a day. An established methodology for decades (e.g., Verbrugge 1980), EDD has been used in a variety of fields, including chronic pain (e.g., Rost et al. 2016), eating behavior (e.g., Debeuf et al. 2018), and emotionality during the COVID-19 pandemic (Moroñ & Biolik-Moroñ, 2021). The benefit of reduced burden of EDD to the participant potentially sacrifices ecological validity when compared to EMA (Schneider & Stone 2016). To make an informed choice between EMA and EDD, a direct comparison is warranted. Broderick et al. (2009) found little differences between both assessment methods after 1 week; however, the findings are limited to the field of chronic pain and fatigue as well as to the period of 1 week. Moreover, results diverged according to the experience being assessed (i.e., pain and fatigue), specifically when comparing the daily equivalence between EMA and EDD. Research on different experiences (i.e., tinnitus) and over longer time periods that usually comprise existent intervention protocols are warranted.

The assessment of tinnitus, the experience of phantom sounds (e.g., high-pitched tone and chirping), relies on self-report only, and a precise evaluation of the experience is paramount for the development of research and symptom management. EMA use within tinnitus is in its infancy, with studies exploring possibilities and limitations of its use (e.g., Schlee et al. 2016; Pryss et

al. 2018; Gerull et al. 2019; Lourenco et al. 2019). However, its superiority to retrospective self-reports has been confirmed (Goldberg et al. 2017). On the other hand, use of EDD, while common for decades, it is rarely utilized as an outcome measure within the tinnitus field. The current study aims at comparing results from EMA and EDD assessments in tinnitus patients undergoing treatment, to provide recommendations for future research. More specifically, EDD mean values are compared to EMA means. Moreover, EMA gathered close (late in the day) to the EDD completion are compared with earlier-in-the-day EMA and EDD. These analyses elucidate if EDD accurately reflects the overall daily picture, as illustrated by EMA.

## MATERIALS AND METHODS

### Participants

As part of a larger project on the effects of cognitive behavioral therapy (CBT) on chronic tinnitus, we collected data from two subsequent clinical studies (duration of 3 months each) in which both assessment methods were used: EMA and EDD. Studies within the project applied a single-case experimental design (SCED) approach. In such a design, a small number of participants are repeatedly and consistently assessed to establish an individual and unique control condition (baseline phase). Afterward, each participant undergoes a manipulation phase (e.g., treatment onset), while maintaining the continuous assessment (for an in depth review of SCED, we guide the interested reader to Morley 2018; Kazdin 2019). As such, these powerful designs rely on the large amount of data from a small number of participants. Each study included six tinnitus patients undergoing specialized CBT for tinnitus which contained a variety of treatment components (e.g., exposure, relaxation, and psychoeducation) delivered twice a week in 2-hour treatment sessions for a total of 20 sessions (for detailed treatment protocol, see Cima et al. 2012). Patients on the waiting list for CBT treatment from the Adelante Department of Audiology and Communication (Hoensbroek, The Netherlands) were sequentially invited to participate in the project. Exclusion criteria comprised: (1) undergoing other tinnitus-related or psychological treatment during the time of the study; (2) commenced the use of hearing aid within 3 months of the start of treatment; (3) commenced or ceased the use of antidepressants, antipsychotics, anxiolytics, Ritalin, hormone replacement therapy, or medication to lower high blood pressure within 3 months of treatment; (4) unable to read and write in Dutch; (5)

disclosed current suicidal intent; or (6) had more than 40 dB of uncorrected hearing loss in one or both ears as measured by calculating a pure-tone average (on the frequencies of 500, 1000, and 2000 Hz).

Patients' tinnitus severity was measured at baseline by the validated Dutch version (Meeus et al. 2007) of the Tinnitus Questionnaire (Hallam et al. 1988), which utilizes 52 items on a three-point scale for a total score ranging from 0 (low severity) to 104 (high severity). Further characterization of the sample is provided through the Dutch (de Beurs et al. 2001) version of the Depression Anxiety and Stress Scale (Lovibond & Lovibond 1995). Consistent of 21-items on a four-point Likert scale, each subscale indicates levels of depression, anxiety, and stress on a score from 0 (low) to 21 (high).

Each of the two studies included were conducted consecutively starting in May 2019 and registered at the Netherlands Trial Register (trial numbers NL7826 and NL8056). Ethical approval was obtained from the Medical Ethical Committee at Maxima Medical Centre, Veldhoven, The Netherlands (METC; NL63262.016.18).

### EMAs and EDD

EMA and EDD data were collected continuously throughout the duration of treatment (3 months). EMA and EDD were collected through purpose-built apps installed on participants' smartphones. One study utilized an in-house developed app (TinNotes) by Maastricht University's Instrumentation Engineering department, while the subsequent study utilized an equivalent third-party app (mEMA; ilumivu, Inc., Cambridge, MA; www.ilumivu.com). EDD assessments were delivered at 8 PM with a 4-hour time limit for completion. EMA questions were prompted seven times during the day, at random points with at least 2 hours in between prompts. Participants had the option to snooze the prompt twice for 5 mins each time, after which the questionnaire would not be available any longer and result in a missing EMA measure for that time-point. Individualized sleeping hours were set so that prompts would not be delivered during those hours. Participants had to complete at least 50% of EDD assessments to be included for analysis. Assessments comprised 16 (EDD) and 17 (EMA) items, presented in random order, of which 12 had content equivalence. Eleven of the equivalent items (Table 1) were rated on a seven-point Likert scale (0–6) and related to either tinnitus experience (i.e., anger, annoyance, avoidance, distraction, fear, invasiveness, pleasantness, and sadness) or overall well-being (i.e., anxiety, happiness,

**TABLE 1. Equivalent items of both assessment types: EDD and EMA**

EDD	EMA
How angry did your tinnitus make you today?	My tinnitus makes me angry
How annoying was your tinnitus today?	My tinnitus is annoying
How anxious were you today?	I feel anxious
How hard did you try to avoid your tinnitus today?	I try to avoid the tinnitus
How distracting was your tinnitus today?	My tinnitus is distracting
How afraid of hearing your tinnitus were you today?	I am afraid of hearing my tinnitus
How happy were you today?	I feel happy
How invasive was your tinnitus today?	My tinnitus is invasive
How pleasant was your tinnitus today?	How pleasant is your tinnitus?
How sad did your tinnitus make you today?	My tinnitus makes me sad
How stressful has your day been?	I feel stressed

EDD, end-of-day diary; EMA, ecological momentary assessment.

**TABLE 2. Demographic characteristics**

P	Age	Gender	Hearing Aid (Time)	DASS-21			Compliance (%)		Tinnitus			
				D	A	S	EMA	EDD	Duration	Location	Type	Severity
1	67	Men	10 yrs	4	0	2	15.8	77.5	2 yrs	Both ears	High pitch	81
2	62	Men	> 30 yrs	8	4	6	51.3	73.6	12 yrs	Both sides of head	High pitch	48
3	59	Men	No hearing aid	2	0	6	70.6	98.8	9 mo	Both ears	High pitch	61
4	65	Men	No hearing aid	0	0	0	89.8	83.8	15 yrs	In the head	Middle pitch	68
5	66	Men	1 wk	12	6	16	64.8	87.5	12 yrs	Right ear	High pitch	57
6	57	Women	No hearing aid	6	10	11	72.9	90.9	35 yrs	Both ears	Buzzing	54
7	64	Men	No hearing aid	1	1	3	90.5	98.5	2 yrs	Right side on the back of the head	High pitch	38
8	43	Men	No hearing aid	13	9	11	76.8	100	11 mo	Whole head	High pitch	80
9	40	Men	No hearing aid	2	0	6	70.6	89.4	6 yrs	Both ears	High and middle pitch	77

*Tinnitus severity measured by Tinnitus Questionnaire (TQ); Depression (D); Anxiety (A); and Stress (S) measured by the Depression Anxiety and Stress Scale (DASS-21).*

and stress). One item (Social Interaction; EMA—“Who are you with?”; Diary—“Who did you spend time with today?”) was descriptive and not included for analysis.

**Analysis**

Pairwise comparisons using Spearman Rank Correlation between EMA and EDD were carried out between all equivalent items. EMA data of each item were plotted through time and a daily mean calculated. To compare EMA gathered

proximally to EDD (delivered at 8 PM) and given the minimum 2-hour gap between EMA prompts, EMA delivered from 6 PM (2 hours before EDD delivery) was separated. Two new EMA means were calculated: (1) early EMA (before 6 PM) and (2) late EMA (after 6 PM). Paired t-tests between EMA means and EDD were conducted and corrected for multiple comparison (Holm 1979). The Holm method controls for family-wise Type I error, with corrections decreasing the threshold of significance for each hypothesis tested. Following convention, we considered

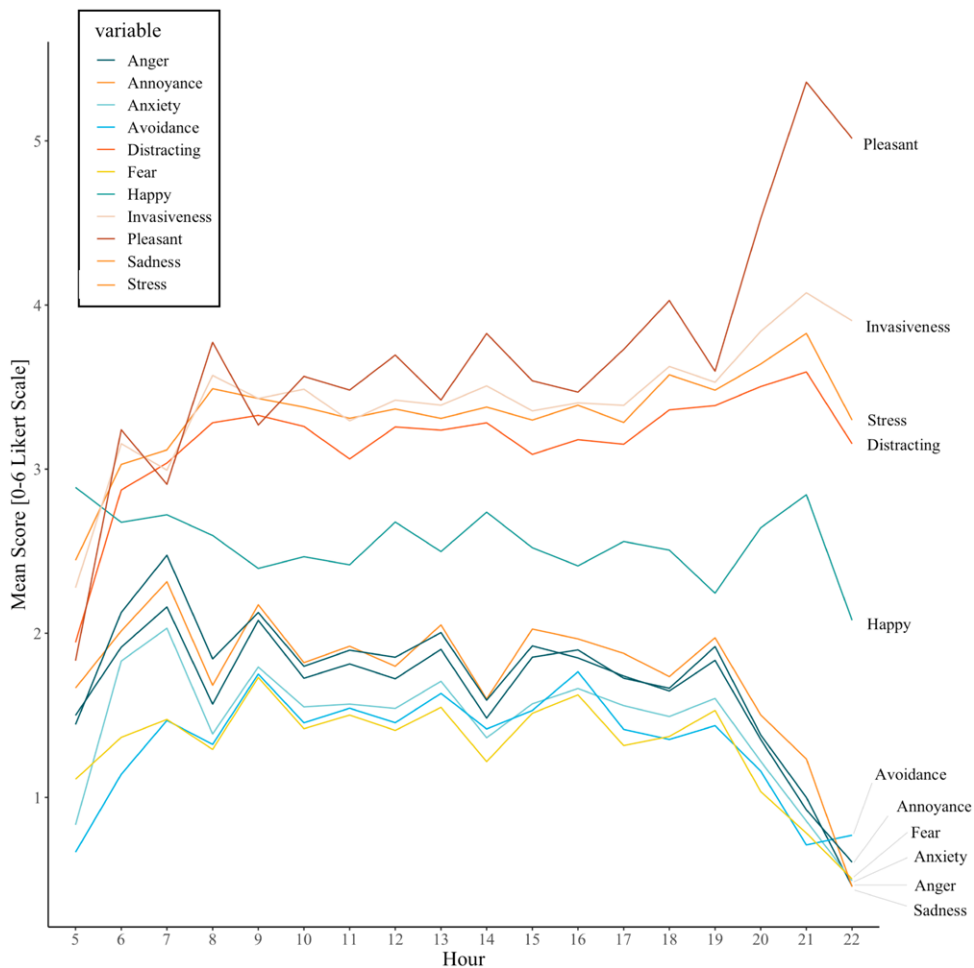


Fig. 1. Mean ecological momentary assessment (EMA) recording per hour.

*p* values below 0.05 “statistically significant.” Pairwise deletions were used to account for missing values. Effect sized was calculated through Cohen’s *D* (Cohen 1988).

Statistical analyses were performed with R version 4.0.1 (R Core Team 2020) with supporting packages (Grolemund & Wickham 2011; Tierney 2017; Wei & Simko 2017; Wickham et al. 2018, 2019; Wickham 2019; Tiedemann 2020).

### RESULTS

Nine participants (88.9% men; mean age = 58.11, SD = 9.98) were included for analysis for a total of 4732 data entries (Table 2). From the original pool of 12 participants, 1 participant dropped out due to personal reasons unrelated to the treatment. An unknown error with the TinNotes app deemed data for two other participants to be unreliable. Data for one participant, who had recently commenced the use hearing aid, were included for analysis as the use of the hearing aid was not continued during treatment.

EMA fluctuations (Fig. 1) show the difference between experience variability according to the time of day (e.g., decrease of tinnitus fear after 7 PM). Strong correlations ( $r > 0.70$ ) were found for all but one (i.e., stress) EMA and EDD items (Fig. 2). Paired *t*-tests (Table 3) indicated significant differences between EMA and EDD daily means on six variables (i.e., tinnitus anger, anxiety, tinnitus invasiveness, tinnitus pleasantness, tinnitus

sadness, and stress). EDD reports for these variables were significantly worse with the exception of tinnitus avoidance, which indicated no differences (Fig. 3). Comparisons between EDD and early EMA (before 6 PM) indicate similar results of worse EDD scores for five variables (i.e., tinnitus anger, anxiety, tinnitus invasiveness, tinnitus sadness, and stress). Moreover, EDD comparisons with late EMA (after 6 PM) indicated worse EDD scores for four variables (i.e., tinnitus anger, anxiety, tinnitus pleasantness, tinnitus sadness, and stress) and improved scores for tinnitus avoidance.

Comparison of early and late EMA indicated significant differences in all but one (i.e., happiness) variables. Items on tinnitus anger, annoyance, fear, invasiveness, pleasantness, and sadness as well as levels of anxiety and stress improved after 6 PM, while tinnitus avoidance and distraction worsened.

### DISCUSSION

This study sets out to compare two similar but different daily measurement methods, namely EMA and EDD in chronic tinnitus patients during a 12-week treatment. Generally, both methods provide quite similar results. All but one item (stress,  $r = 0.69$ ) showed strong correlations between EMA and its EDD counterparts ( $r > 0.77$ ). Nevertheless, EDD stress reports are significantly higher than early-in-the-day EMA measures (where mean stress levels were at their highest). EDD painted a worse

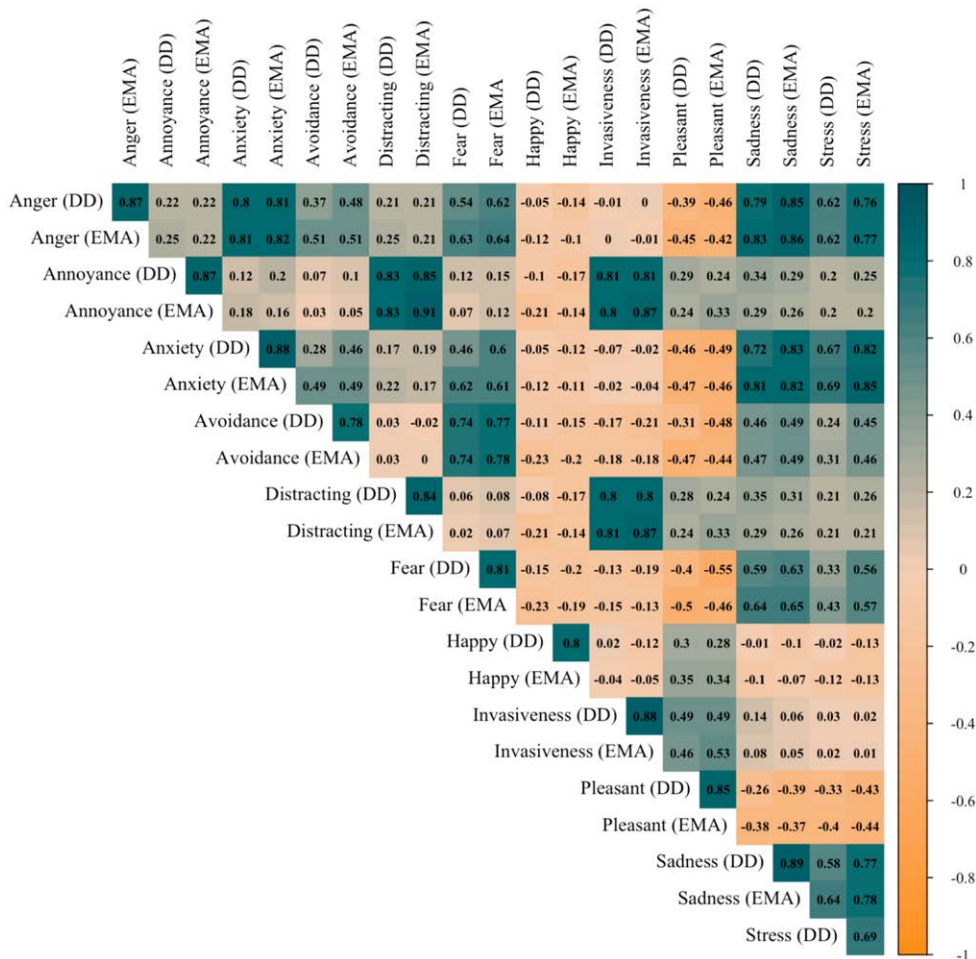


Fig. 2. Correlation coefficient strengths.



picture for another five variables when compared to EMA (i.e., tinnitus anger, anxiety, tinnitus invasiveness, tinnitus pleasantness, and tinnitus sadness). EDD reports favored negative experiences rather than recent experiences (i.e., EMA after 6 PM). Broderick et al. (2009) found similar results when comparing EMA and EDD of pain and fatigue experiences. Such occurrence is akin to the “experience memory gap” (Miron-Shatz et al. 2009), where recalled symptoms are reported as worse when compared to real-time in the moment assessments (i.e., EMA). Such memory biases were studied in a recent review (Van Den Bergh & Walentynowicz 2016), indicating that pain and fatigue

experiences are overreported when assessments rely on longer recall periods. While these findings are significant in the field of self-report assessments, no study with tinnitus complaints was included in the review and parallels must be drawn with caution.

The large sample of data provided by novel methodological approaches (e.g., EMA, EDD, and SCED) present both statistical opportunities and issues not commonly encountered. Despite correcting for multiple comparisons (i.e., Holm 1979), which decreased the threshold for significant results, the findings are still affected by the large number of data and traditional  $p$  value selected (i.e., 0.05). As such, more conservative

**TABLE 3. Paired sample t-tests with adjusted  $p$  values for equivalent variables of EMA and EDD on a Likert scale (0–6)**

	Mean EMA (SD)	Mean EDD (SD)	$p$	Cohen's D
Anger	1.756 (1.723)	1.870 (1.748)	<0.001*	0.065
Annoyance	3.382 (1.931)	3.414 (1.932)	0.156	0.017
Anxiety	1.575 (1.42)	1.648 (1.44)	<0.001*	0.050
Avoidance	1.454 (1.477)	1.422 (1.451)	0.156	-0.022
Distracting	3.242 (1.891)	3.202 (1.855)	0.110	0.065
Fear	1.403 (1.399)	1.425 (1.431)	0.170	0.016
Happy‡	2.503 (1.308)	2.507 (1.247)	0.815	0.003
Invasiveness	3.461 (1.895)	3.522 (1.805)	<0.001*	0.033
Pleasant‡	3.649 (2.271)	3.587 (2.28)	0.030†	-0.027
Sadness	1.869 (1.679)	1.956 (1.697)	<0.001*	0.051
Stress	1.831 (1.576)	2.102 (1.587)	<0.001*	10.172
	Mean early EMA (SD)	Mean EDD (SD)	$p$	Cohen's D
Anger	1.885 (1.777)	1.997 (1.791)	<0.001*	0.063
Annoyance	3.337 (1.954)	3.372 (1.939)	0.348	0.018
Anxiety	1.690 (1.447)	1.750 (1.452)	<0.001*	0.042
Avoidance	1.563 (1.514)	1.550 (1.485)	0.974	-0.009
Distracting	3.199 (1.912)	3.175 (1.858)	0.920	0.063
Fear	1.507 (1.43)	1.532 (1.463)	0.580	0.017
Happy‡	2.52 (1.354)	2.527 (1.283)	0.974	0.006
Invasiveness	3.374 (1.893)	3.438 (1.792)	0.007†	0.034
Pleasant‡	3.408 (2.294)	3.377 (2.3)	0.920	-0.013
Sadness	2.007 (1.711)	2.066 (1.726)	<0.001*	0.035
Stress	1.988 (1.605)	2.211 (1.594)	<0.001*	10.140
	Mean late EMA (SD)	Mean EDD (SD)	$p$	Cohen's D
Anger	1.386 (1.5)	1.503 (1.564)	<0.001*	0.076
Annoyance	3.511 (1.857)	3.534 (1.906)	1	0.013
Anxiety	1.248 (1.285)	1.353 (1.361)	<0.001*	0.079
Avoidance	1.142 (1.317)	1.053 (1.28)	0.012†	-0.068
Distracting	3.365 (1.826)	3.276 (1.847)	0.080	0.076
Fear	1.101 (1.259)	1.119 (1.287)	1	0.014
Happy‡	2.456 (1.164)	2.448 (1.134)	1	-0.006
Invasiveness	3.709 (1.881)	3.762 (1.82)	0.296	0.029
Pleasant‡	4.339 (2.054)	4.19 (2.11)	<0.001*	-0.072
Sadness	1.475 (1.517)	1.639 (1.572)	<0.001*	0.106
Stress	1.379 (1.397)	1.789 (1.523)	<0.001*	10.279
	Mean early EMA (SD)	Mean late EMA (SD)	$P$	Cohen's D
Anger	1.87 (1.748)	1.756 (1.723)	<0.001*	Paired Cohen's D could not be computed due to an unequal number of measures
Annoyance	3.414 (1.932)	3.382 (1.931)	0.003†	
Anxiety	1.648 (1.44)	1.575 (1.42)	<0.001*	
Avoidance	1.422 (1.451)	1.454 (1.477)	<0.001*	
Distracting	3.202 (1.855)	3.242 (1.891)	0.004†	
Fear	1.425 (1.431)	1.403 (1.399)	<0.001*	
Happy‡	2.507 (1.247)	2.503 (1.308)	0.163	
Invasiveness	3.522 (1.805)	3.461 (1.895)	<0.001*	
Pleasant‡	3.587 (2.28)	3.649 (2.271)	<0.001*	
Sadness	1.956 (1.697)	1.869 (1.679)	<0.001*	
Stress	2.102 (1.587)	1.831 (1.576)	<0.001*	

\* $p < 0.001$ .

† $p < 0.05$ .

‡Inverted item.

EDD, end-of-day diary; EMA, ecological momentary assessment.

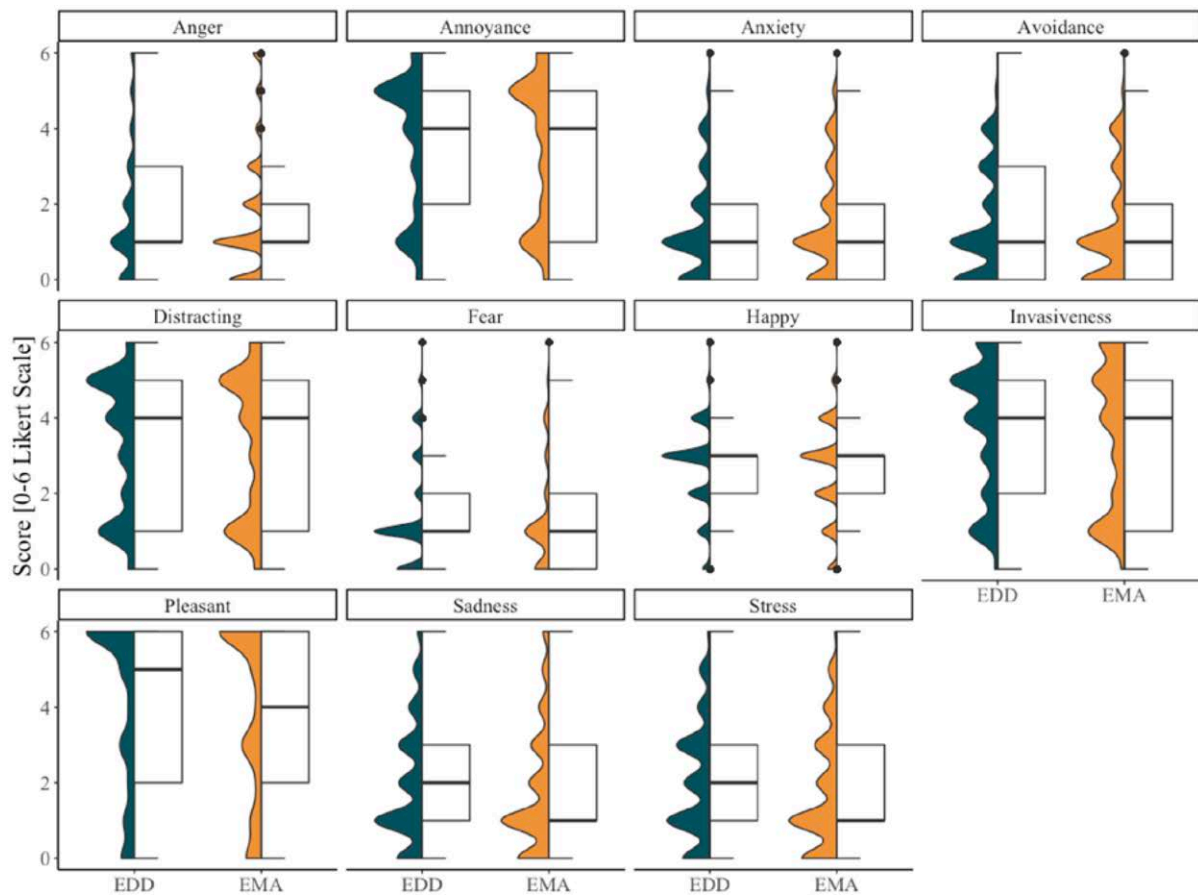


Fig. 3. Ecological momentary assessment (EMA) and end-of-day diary (EDD) distribution and box plot per variable.

approaches that are beyond multiple comparison corrections may provide a more accurate picture of the results (i.e., lower  $p$  value thresholds). In the current study, the largest significant mean difference found in tinnitus-related variables was tinnitus anger (1.63%), with stress levels (3.87%) holding the largest, although small, difference in well-being variables. Whether these statistical differences are clinically relevant are therefore questionable. Furthermore, while EDD results may have differed from early or late EMA, the daily EMA mean accurately reflected the remaining variables (i.e., tinnitus annoyance, tinnitus avoidance, tinnitus distraction, tinnitus fear, and happiness).

An exception was found in happiness levels, which did not significantly differ between EMA and EDD measures at any point. EMA and EDD measures of happiness strongly correlated ( $r = 0.80$ ) even though both measures correlated weakly ( $r < 0.24$ ) with other variables. Despite this seemingly independent level of happiness from other experiences (e.g., tinnitus anger, tinnitus annoyance, anxiety, and stress), accurate assessment of happiness remains a challenge, with the very definition of happiness still debated (Ludwigs et al. 2019). As such, interpretations of happiness stability and independence are limited.

The choice of variables to be measured, while theoretically driven and based on specialist consensus, lacked the insight from other key stakeholders and may further benefit from initiatives acknowledging patient preferred outcomes (i.e., Hall et al. 2018). An added benefit of EMA and EDD measures is that it

may conform with the push for individualized medicine (Schork 2015; Senn 2018) due to its flexibility in incorporating different items. Therefore, while the outcomes used in the current research are relevant within its theoretical framework, they are limited by the pool of specialist used to create the items. Further research utilizing a broader consensus of outcome variables, as suggested by Hall et al. (2018) may increase the relevance and use of EMA and EDD. Moreover, the choice of a seven-point Likert scale, while not directly inspired by standardized tinnitus self-report assessments, was made due to technical limitations of the TinNotes app. Further research incorporating other scales, specifically visual analog scales, are recommended.

Additional limitations include the high proportion of men 40 years or older (88.89%) in the sample, limiting the generalizability of the findings. The homogeneous sample follows epidemiological trends in tinnitus, with 80% of tinnitus diagnosed after the age of 40 (Stohler et al. 2019) and higher incidence detected in men (Fujii et al. 2011; McCormack et al. 2014, 2016). Despite the limitations, the current results add important knowledge on long-term EMA versus EDD comparisons and provide insights into using these methods in tinnitus patients (in addition to chronic pain and fatigue)

## CONCLUSION

Generally, EDD and EMA provide similar data. EDD measures significantly differed from EMA daily averages for six out

of 11 variables: tinnitus anger, anxiety, tinnitus invasiveness, tinnitus pleasantness, tinnitus sadness, and stress. The differences support the previous literature which found that longer recall periods associate with worse symptom/experience recollection. Despite their statistical significance, the effects were small and may be attributed to the large number of data entries. As such, the minor differences may not justify EMA as the measurement of choice as the added burden to participants may be of ethical or theoretical concern. When these arise, EDD provides a viable alternative since it accurately and closely reflects daily-life experiences as measured by EMA daily mean. Nonetheless, when the use of EMA is necessary the minor differences found in the current study do not justify a correction of the data collected. EMA may better suit the need of closely investigating cyclical tinnitus patterns (e.g., sleep/awake) or possible daily correlates (e.g., work environment, presence of triggers). The knowledge of specific correlates allows for the recognition of maladaptive patterns and emotional reactions which may be addressed during treatment. Moreover, the use of repeated assessments (i.e., EMA and EDD) is vital in the application of SCEDs which are tailored to the push for individualized research and treatment (Schork 2015).

The continuous development and understanding of tinnitus assessment must be prioritized as the lack of an objective measure of tinnitus entails an over-reliance on patient self-reports for research and treatment. Future research on accurate measurements of the underlying mechanisms of the tinnitus experience may pave the way for a broader understanding about the onset, maintenance, and recovery of tinnitus disability.

## ACKNOWLEDGMENTS

This project has received funding from the European Union's Horizon 2020 research and innovation program under the Marie Skłodowska-Curie grant agreement number 722046. R.F.F.C. received funding from the Innovational Research Incentives Scheme Veni, from the Netherlands Organisation for Scientific Research (NWO). J.W.S.V. is supported by the Asthenes research program "From Acute Aversive Sensations to Chronic Bodily Symptoms," a long-term structural Methusalem funding (METH/15/011) by the Flemish government, Belgium.

The authors have no conflicts of interest to disclose.

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Received August 11, 2020; accepted February 25, 2021; published online ahead of print April 26, 2021.

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