Research Article

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Attention or Heart Rate: A Preliminary Study towards Integrating the Top-down and Bottom-up Processes in Estimating the Apnea Durations

Dikkat Mi Nabız Mı: Apne Sürelerinin Tahmin Edilmesinde Yukarıdan Aşağıya ve Aşağıdan Yukarıya Süreçlerin Bütünleştirilmesine Yönelik Bir Ön Çalışma

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ABSTRACT

Accurate perception of time is vital in some athletic activities such as free-diving performance. The exact mechanisms underlying the correct estimation of long intervals using different time estimation paradigms are still an issue to be solved in psychology. To this end, in the current study, by using a prospective paradigm, examined top-down and bottom-up predictors of 25, 50, and 75 seconds of apnea durations. Eleven free-diving athletes performed the target apnea estimations in two experimental conditions: apnea in the air and immersed apnea. In line with our integrative perspective, we obtained heart rate values, attentional control capacities, and affectivity states of the participants, and analyzed the relationship of these with the directional errors of three target apnea estimations. A series of within-participants analyses found the following: first, the heart-rate alone is not the only factor influencing time estimation during long intervals; second, attentional capacity and positive affect contributed to the accuracy of time estimation in a non-constant fashion; third, these three variables affected the accuracy of time estimation differently according to the modality and the duration of the target interval; and fourth, the participants were most accurate in estimating the time during 75s of apnea in the immersed condition.

Keywords: *Time estimation, Attention, Heart rate, Internal clock, Apnea*

ÖZ

Serbest dalış performansı gibi bazı aktivitelerde zamanın doğru algılanması hayati önem taşımaktadır. Saniyeler ile ifade edilebilecek görece uzun zaman aralıklarının doğru tahmininin altında yatan kesin mekanizmaların anlaşılması, psikolojide çözülmesi gereken konulardan biridir. Bu amaçla, mevcut çalışmada, prospektif bir paradigma kullanılarak, 25, 50 ve 75 saniyelik apne sürelerinin yordayıcıları incelenmiştir. Çalışmanın verileri, iki deneysel koşulda, on bir serbest dalış sporcusunun hedef apne tahminlerini havada ve suda (daldırılmış) yapmaları yolu ile elde edilmiştir. Katılımcıların kalp atış hızı değerleri, dikkat kontrol kapasiteleri ve duygu durumlarının üç farklı hedef apne tahminindeki doğruluğunun incelendiği bu çalışmada: zaman tahminini etkileyen tek faktörün kalp atış hızı olmadığı; dikkat kapasitesi ve olumlu duygudurumun lineer olmayan bir tarzda zaman tahmininin doğruluğuna etki ettiği; yordayıcı olarak kullanılan bu üç değişkenin, deney koşuluna ve hedef aralığın süresine göre farklı şekilde etkili olduğu ve son olarak, katılımcıların en doğru zaman tahmininin, bu çalışmada kullanılan en uzun zaman aralığı olan 75 saniye suda apne olduğu bulunmuştur.

Keywords: *Zaman tahmini, Dikkat, Nabız, İçsel zamanlama, Apne*

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INTRODUCTION

Accurate time estimation is a useful personal resource for effective time management skills, but it is rarely vital in the daily lives of humans. However, accurate time perception is a crucial factor in certain activities, such as free-diving, because athletes should estimate the time elapsed under the water to achieve the best performance without endangering their lives. Although time estimation studies remain unfinished business in psychology, every-day practices may force researchers to shed light on the issue so that the results can be used in real life. Many elite athletes have died during free-diving competitions or trainings, possibly because they failed to accurately estimate the time spent under the water (Skolnick, 2013).

Traditionally called "skin-diving," free-diving is also called "breath-hold diving." It involves taking a breath before plunging below the water surface to swim immersed for a certain, usually long period of time. Through special breathing techniques and practice, free-divers are often able to extend their underwater times (Dimmock, 2007; United States Apnea Association [USAA]). Static apnea is "a branch of competitive free-diving which includes performing a maximum duration of voluntary apnea without movement for a period of time declared beforehand and if possible, going beyond this time" (World Confederation of Underwater Activities, CMAS). The best performance of static apnea is reported to be 10 minutes and 45 seconds (11 November 2017, CMAS). In the World Freediving Indoor Championship (14 June 2022 Belgrade) the static apnea results varied between from 2 minutes 38 seconds to 9 minutes 12 seconds (CMAS). It is obvious that the accurate estimation of the elapsed time during apnea performance, i.e., the correct perception of time, has a critical role. However, to date the studies of time perception has generally focused on the durations in the milliseconds-to-seconds range, and how humans perceive longer durations, i.e., minutes, still remains unclear.

Human temporal processing without holding one's breath alone, is a complex issue (Matthews and Meck, 2014; Ogden et al., 2011; Ogden et al., 2021) and several models have attempted to understand how humans represent, perceive, and predict time. Despite the abundance of theoretical models, time perception seems to have failed to play a central role in the general theory of behavior (Hancock and Rausch, 2010); yet, it has proven to be quintessential because of its presence in every human action (Block, 1990). When the time estimation (TE) paradigms (i.e., retrospective, prospective and temporal generalization) and modalities (i.e., visual, auditory, and tactile), as in the case of free-diving, researchers realized the complexity of the event (Matthews, 2013): the results of time perception and TE studies produce were inconsistent (Matthews and Meck, 2014; Wearden and Jones, 2013). Recently, shared processing models suggest that, magnitudes of different sources are processes by shared neural mechanisms. A recent study however, failed to completely support this notion (Ogden et al., 2021).

The scalar timing model (Gibbon et al., 1984) is still one of the most widely accepted models in TE research. This model is based on the earlier internal-clock hypothesis and asserts that time duration estimation is a product of the information processing system, which consists of clock-memory-decision (see Gibbon and Church, 1990; Wearden, 1999; Zakay and Block, 1995, for a full description of the model). Since TE can be affected by any change in the components of the system (Allan, 1998), if there is any change in the pacemaker system, this can lead to a change in the TE itself. According to the scalar timing model, heart rate (HR) is one of the factors that also affect TE because it is used as a "pacemaker." Any change in the HR, therefore, may cause a change in TE (Rammsayer et al., 2001).

Because time perception encompasses different experiences of subjective time, the results of studies reveal different outcomes depending on the conceptualization of the subjective experience of time used to define these experiences. For example, duration estimation (interval length) and the perceived speed of time passage are two distinct subjective time experiences (Block, 1990; Wearden, 2008), while duration estimation can be studied using either prospective or retrospective paradigms. Depending on the paradigm and the task used to estimate the time, the results of studies show diverse findings (Block and Zakay, 1997; Block et al., 2010; Gibbon et al.,1988). For example, Sucala et al. (2011) found that, in the prospective paradigm, time is estimated to be shorter if the task is difficult, in contrast to a retrospective paradigm where the time is estimated longer if the task is difficult. Similarly, Wearden and Jones (2013) have drawn the attention of the researchers to the differences in the internal clock and state that the between-group differences in terms of the timing task may be difficult or even impossible to distinguish in practice. Eagleman (2008) argued that the idea of a clock-like counter has found little support in physiology and, thus, a new model is needed.

The over -or- underestimation of the actual time is still an issue and being explained by the attention-based internal clock models (Block and Zakay, 1997). The attentional gate model is currently the most widely accepted model specially in understanding prospective timing (Zakay and Block, 1997). According to the attentional gate model, greater attentional resources are required for the accurate processing of longer time durations. As a result, attentional resources are consumed by the processing of the nontemporal material, a lower level of attention is available for time processing and, as such, some pulses are lost and time is judged as shorter (Block et al., 2010; Bi et al., 2013). In a similar fashion, segmenting the time interval increases the subjective perception of duration (Matthews, 2013), and when time dimension is relevant in a task (Sucala et al., 2010), participants pay more attention to the process of timing and make longer interval estimates (Sucala et al., 2011). Lamotte and colleagues (2012) reported that the magnitude of distortion of TE in dual tasks decreased with the increase of attentional control capacities of the participants. Additionally, mood or affective status of the participants was shown to influence time perception. Many studies reported that the duration of the negative-valance stimulus (angry/fearful faces) was overestimated (Tipples, 2008) and this is related with specific negative emotions experienced by the participants (Tipples, 2011), such as, the intensity of fear was found to modulate the magnitude of time distortions (Buetti and Lleras, 2012).

The last problem seen in TE studies is the durations examined. Many experimental studies which used different methods (such as temporal generalization, bisection, verbal responses and timed behavior) generally examined the durations in the milliseconds -to- seconds range. Bar-Haim et al. (2010) report that several studies have hypothesized different mechanisms underlying prospective estimations of durations for different intervals. While for brief durations (less than 2 seconds), the arousal levels seem to be more dominant; for longer durations exceeding 2-3 seconds, the attentional processes dominate the TE mechanisms. Some of these studies suggest that, over the range about 0.5-2 seconds, the Weber fraction is not constant, and that the scalar property of timing is a subject of debate despite conflicting findings (Grondin, 2012; Matthews and Meck, 2014) and, so future research needs to focus on longer durations (Wearden, 1999). The perception of short durations of time as in milliseconds and seconds has theoretical value but the need to examine TE of longer durations is crucial in daily life.

As stated earlier, the TE process is a dynamic, variable, and complex one; According to Wearden “something in the timing system contains variance” (1999, p.7). The source of variability may lie within any component of the internal clock, the pace maker, the switch, short-term memory or long-term memory (Wearden and Grindrod, 2003). In the presence of this complexity, although it is challenging to study the subjective experience of a time interval, as Wearden suggested “… methods have to be devised to dissect out possible variance sources, even though usually these cannot be studied completely on their own (Wearden, 1999, p. 8). Despite such an apparent need, research on this topic has been scarce. In the following, we summarize the key findings of research regarding apnea-time estimation and, apnea-heart rate relationship.

The Apnea - TE Relationship: Regarding the relationship between HR and TE during apnea, a common finding of the studies is that TE during apnea is significantly greater than non-apnea conditions (Jamin et al., 2004a; Di Rienzo et al., 2014). The underestimation of the elapsed passage of time during apnea is interpreted as follows: apnea-induced bradycardia leads to a decrease in the HR which is used as an internal pacemaker, and this slow-down in the speed of the pacemaker leads to a shorter experience (or underestimation) of the real time. Immersion or diving adds other cardiovascular and metabolic changes to the HR, and TE in immersion accelerates the HR reduction (Jamin et al., 2004a).

However, the HR-TE relationship was found to be not as direct as it first appeared. For example, in Jamin et al.'s study (2004a), researchers reported three unexpected findings: first, TEs in three subsequent apnea immersion trials were significantly different from each other; that is, TEs increased consistently between the first and third trials although the HRs did not change. Second, the apneic bradycardia at rest did not differ between apnea in the air and apnea in immersion conditions. Third, TEs in normal breathing with exercise and apnea with exercise were not different although the HRs were significantly higher in normal breathing with exercise condition. They concluded that such unexpected findings might be due to short time intervals between the TEs, suggesting that the physiological arousal theory alone cannot explain the difference but, instead, the change might be attributed to the physical activity according to the model of human temporal processing along with the external stimulus. Referring to the Jamin et al.'s studies (2004a; 2004b), Di Rienzo and colleagues (2014) used the unique method of apnea to determine the effect of past motor experience and the internal clock process on TE in two experimental conditions. Fourteen breath-hold divers, physically and mentally (through mental imagery) performed two swimming tasks (placement of iron sticks) with apnea and with normal breathing. As expected, compared to mental imagery with normal breathing conditions, performing mental imagery while holding one's breath increased the durations (underestimation of the time), and this increase in the estimated time correlated with HR decrease. Unexpectedly, however, longer estimations of time were obtained during both apnea and normal breathing conditions of physical performance. This result, together with Jamin et al.'s findings, suggested that the HR change is variable in apnea and needs to be examined in detailüü.

HR Variability During Apnea: The diving response, a reduction in HR, is highly variable among humans (Andersson, et al., 2002; Caspers et al., 2011). The human diving response involves bradycardia and is a major physiological adaptation, allowing humans to endure the lack of oxygen during apnea (Foster and Sheel, 2005). Although there are some individual differences in the diving response (Baranova et al., 2003; Caspers et al., 2011), it is known that elite breath-hold divers exhibit an intense diving response (Ferrigno et al., 1997). The common features in HR reduction during apnea is as follows. First, there are clear differences between HR reduction during apnea in the air and apnea in immersion. While HR in apnea in the air condition is slower, a more profound diving response is seen in apnea in immersed conditions (Andersson et al., 2002; Caspers et al., 2011; Jung and Stolle, 1981), varying between 33% (Andersson et al., 2002) and 44% reduction in HR (Lemaitre et al., 2005). Second, at the beginning of monitoring in almost all of the studies, HR tends to increase slightly (Caspers et al., 2011; Lemaitre et al., 2005). Third, at least 30s is required to see the full effect (Caspers et al., 2011) and maximal bradycardia is seen around 50s of apnea. Additionally, excitation and training leads to some fluctuations in HR, which shows rapid decrease around 50s, recovers partially around 75s and there is a decrease again afterwards (Andersson et al., 2002). Finally, some studies have suggested an increase in HR just before the apnea-breaking point, which is reached once the diver feels the apnea should not continue (Andersson and Evaggelidis, 2009).

To summarize, the findings from three lines of research: psychology, sports science, and physiology indicate that, despite all its complexities and variance, the mechanisms underlying accurate TE needs to be studied for both theoretical purposes and practical necessities. We believe that free-diving is one of such activities where theory and practice meet. Although the TE literature has produced inconsistent results, it is possible to see this variance from a unifying perspective. From the integrative point of view, we conclude some of the findings provide data for the validity of the bottom-up processing of the information during TE, while the others show that top-down processing is in charge and this information is integrated and used in a (possibly) unique fashion to accurately estimate time. Similar to the resolution of the major theoretical issue whether perception relies directly on information present in the stimulus (Gibson, 1966), i.e., the HR in time perception, or depends on the perceivers expectations or qualifications (Gregory, 1970) i.e., attention and affect in time perception, an integrative model (Neisser, 1976; Tulving, 1972) is needed in time perception literature. We believe that an integrative model, which encompasses both top-down and bottom-up factors in time perception, is needed to help overcome some of the obstacles mentioned above.

As an initial attempt at integration, we devised a study where both top-down and bottom-up variables of time perception were studied simultaneously. By considering the research findings drawing on the scalar timing theory, HR was selected as the bottom-up variable and manipulated the pacemaker speed by means of voluntary apnea. To this end and in order to understand the role of HR in the TE process, we conducted two experiments in which free-diving athletes performed static apnea both in the air and while in immersion. By considering the research findings drawing on cognitive models of time perception and attentional gate model (AGM), the authors intended to see the effect of two top-down variables: attention and affectivity. By keeping the importance of prospective TE in monitoring the temporal dimension of ongoing performance (Zakay et al., 1999), we used the prospective paradigm where the participants know in advance that the task will involve estimating the length of a temporal interval together with a production method as a temporal procedure. Finally, by considering both theoretical needs and practical necessities, we examined the accuracy of estimations in 25s, 50s and 75s of apnea.

Based on this information, we propose the following hypotheses:

1. Both the duration and the modality of apnea influence HR.
    a. HR values obtained during apnea in immersion will be lower compared to HR values obtained during apnea in the air.
    b. The HR values obtained in 50s and 75s of apnea will be lower compared to HR values obtained in 25s of apnea.
2. The estimation of time duration during apnea in the air will be shorter compared to estimations of time duration during apnea in immersion.
3. HR, attention, and affectivity will determine the accuracy of the time estimation differently.
    a. For short intervals (25s), attention and affectivity better predict the accuracy of time estimation.
    b. For longer intervals (50s and 75s), HR better predicts the accuracy of time estimation.

METHOD

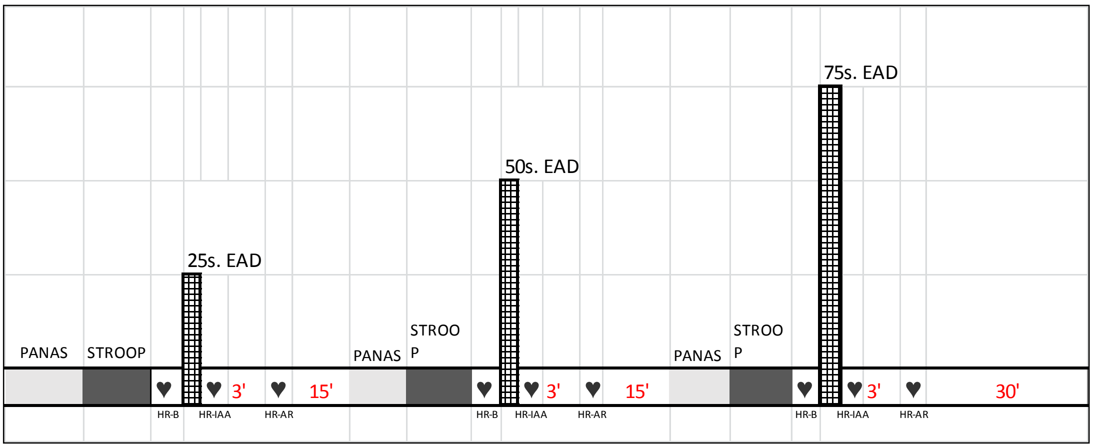
Participants: Eleven free-diving athletes who were active members of a well-known state university's sub-aqua team voluntarily participated in the study. Five of the participants were female and six of them were male. The mean age of the participants was 24.73 (min= 22, max= 28, SD= 2.19). The average years of their free-diving background was 2.86 (min= 1, max= 6, SD= 1.58).

Design and Procedure: The data were collected by 11 experimenters who had received a two-hour training and practice course prior to the data collection on measuring the HR, presenting the target TEs, and all other procedures to be followed during the experiments. The experiments were conducted in an Olympic-size swimming pool, where the water and air temperature was measured constantly. The free-divers participated in two different experimental modalities in two separate days with a week's interval; these were static apnea in the air (AA) and static apnea immersion (AI). In the AA modality, the participants performed the apnea task while comfortably sitting on a chair by the pool and without any exercise. In the AI modality, they undertook the same task inside the pool, where their whole body and face was immersed in the water.

In each modality, the free-divers participated in three sets of experiments, nine sessions in total for each modality. An average session lasted for about 45 minutes to complete, were separated by 15min breaks wherein the participants rested. The sets were separated by 30min breaks, during which they rested and ate if they wished. The collection of the entire data in two modalities and a total of 18 sessions lasted for about 13 hours. The order of experimental modalities and the experimental tasks, except for the Stroop task, was counterbalanced for each participant to eliminate the order effect. Two professional life guards were onsite and available in all sessions in case of an emergency. Figure 1 represents an example of a typical experimental session. The free-divers participated in nine such sessions in each of the AA and AI modalities.

Figure 1

A Sample Experimental Session



Experimental tasks: The participants performed two different tasks; these are: Stroop task and Estimation of Apnea Durations (EADs).

Stroop task: In the current study, standard Stroop cards and stimuli were used (Stroop, 1935). Four A4 size cards (21 cm X 29,7 cm) were used as stimulus materials. The stimuli consisted of four color names (red; blue; green; yellow) written in red, blue, green, or yellow. Card 1 consisted of 24 color names printed in black ink. Card 2 consisted of 24 color names printed in congruent colors (e.g., the word "red" was printed in red ink). Card 3 consisted of 24 colored stimuli (XXX), each Ariel 36-point black in size. On Card 4 were 24 color names printed in a different color of ink (e.g., the word "red" was printed in blue ink). All participants were tested individually and instructed to read out the word (Card

1 and 2) and name the color of each stimulus (Card 3 and 4) as quickly and accurately as possible. The experimenter recorded the time to complete the task by a stop-watch. The response time and number of errors and corrections were recorded by the experimenter.

EADs: The second task of the participants was to estimate apnea durations for 25s, 50s and 75s using the prospective paradigm. By means of the "production" method (Jamin et al. 2004), the experimenter provided the target duration and the participants were asked to produce the same time interval. In detail, they were required to hold their breath as long as the target apnea duration and signal by hand once they finished the task. The time to complete the EAD task was recorded by the experimenter with a stop-watch.

The order of the target apnea durations was randomized in order to eliminate an order effect and no performance-related feedback was given. In order to increase the reliability of the procedure, the participants repeated the EAD task for each target apnea duration three times. We obtained nine different EADs for each target apnea duration in each modality. In the analysis, the mean values of nine trials were used.

***Experimental Modalities*:** As stated above, the participants performed the Stroop and EAD tasks in two experimental modalities: Apnea in the air (AA) and apnea immersed (AI). The design and procedure are described in detail as follows.

Apnea in the air (AA): The participants comfortably seated on a chair in their swimming suites by the pool. First, they completed the questionnaire regarding their demographical information and completed an affectivity scale. When the participants felt ready, the experimenters conducted the Stroop test. To form the baseline HR (HR-B) before the EAD, their HRs were measured by the experimenters. Once ready, they started the EADs for the three target intervals: 25s, 50s, and 75s, each target interval in one session. Immediately after the EAD, their HRs were measured again (HR-IAA). After three minutes of resting, their HR measures were retaken (HR-AR). The participants repeated the EAD task for the same target interval two more times by following the same procedure.

Apnea immersed (AI). The same procedure in AA was followed in AI, with the only difference that the participants were inside the pool this time where their whole body except for the head was immersed during the measurement of HR. The EAD tasks were performed in the same way with both body and face immersed bottom wise horizontally.

Measures and Materials:

Positive Negative Affectivity Scale (PANAS): PANAS developed and validated by Watson et al. (1988) is a reliable, valid, and efficient means of assessing the two important dimensions of mood; positive and negative affect. The scale consists of two sub-scales; PANAS PA (positive affect) and PANAS NA (negative affect). Each subscale consists of ten items as markers of either PA or NA. The scale uses a 5 point Likert-type scoring system (0 = not at all, 4 = extremely); the subscales are sensitive to fluctuations in mood when used with short-term instructions (e.g., right now or today).

Stroop Color-Word Interference Test: The Stroop Color-Word Interference Test in its many variations is a widely used measure and is considered to be the "golden standard of attentional measures" (MacLeod, 1992). It is also considered a general measure of cognitive control or executive functioning (Halin et al., 2014, Hutchison, 2011). Although different Stroop test versions have been developed (e.g., Comalli et al., 1962; Trenerry et al., 1989; Van der Elst et al., 2006), the basic paradigm of the Stroop test has remained the same. It consists of a color-name reading task, a color-naming task, and an interference task. In the current study, the standard method to assess Stroop interference was used to calculate the interference difference score (ID) -that is, the difference between the response time to complete color-name (C) and color–

word (CW) scores. A lower difference score means less interference from incongruent words when naming the colors in the color–word condition. The error and correction scores were obtained in the same way by calculating the difference of error and correction scores between C and CW scores (see MacLeod, 1991; Lansbergen et al., 2007).

Variables**:** Four main groups of variables were obtained in AA and AI modalities. These are: EADs, HR, Stroop Interference scores, and PANAS scores. In the following details pertaining to each group are presented under separate headings. Table 1 shows the means and standard deviations of variables used in the study.

EADs: In each of the 18 experimental sessions, we collected the EADs data in three levels - 25s, 50s, and 75s - and formed six EADs as dependent variables: (1) 25s EAD in AA, (2) 50s EAD in AA, (3) 75s EAD in AA, (4) 25s EAD in AI, (5) 50s EAD in AI, and (6) 75s EAD in AI. In the repeated-measures analyses, we used three EAD levels in AA and AI as factors. For EADs, following a standard procedure, the estimated times were converted into measures representing % of directional errors (Err.) (Khan et al., 2006). In the transformed data set, the error values over 0 represent a temporal overestimation and those under 0 as underestimation of the targeted interval. A directional error of 0 represents accurate TE. In the regression analyses, six EAD's directional error scores (EAD Err.) were used as dependent variables.

HR: As the TE literature in apnea suggested (see, for example, Heusser et al., 2009), the HRs of the participants were recorded three times: at the baseline (B) before the EAD tasks, immediately after apnea (IAA), and after three minutes of resting (AR). It was assumed that the HR values after 3min of rest indicate the presence of bradycardia during the apnea performances. Consistent with Andersson and Evaggelidis (2009) suggestions stated as divers should be observed for at least 20-40s, for safety reasons, we allowed three minutes of rest (Joulia et al., 2003), which was found to be suitable by earlier researchers (e. g., Heusser et al., 2010). The experimenters manually counted the pulses of the participants using a stop-watch for 10 seconds. The HR measures are in pulse/per 10s. For each target EAD interval in each experimental modality, we obtained three HR variables: HR-B, HR-IAA, and HR- AR. In the repeated-measures analyses, we used three HR levels in AA and AI as factors. In the regression analyses HR values were used as predictor variables.

Stroop interference scores: Two types of Stroop scores were obtained. These are Stroop interference difference score [Stroop I (d)] and Stroop interference error [Stroop I (e)]. Both scores were obtained in the same way, i.e., by calculating the difference of response time and correction scores between C and CW scores, respectively.

Initial Analyses: Throughout the analyses, a within-participants repeated-measure design was used. Because the repeated-measures ANOVA requires the assumption of sphericity, we first examined the Mauchly's test of sphericity in all analyses. The assumption was met in all the analyses, except for Stroop I (e). Therefore, this score was not used any further. For post-hoc comparisons, we conducted one-sample and paired-sample *t-test*s. To test the suitability of our data for the further statistical analyses, we examined variables in terms of normality, homogeneity and multicolinearity. As it was explained in Design and Procedure section in detail, we obtained 9 distinct and independent data points per variable for each of the participant; this resulted in 99 cases. Power analyses were performed concerning the adequacy of the number of case measurements (sample size) prior to conducting further univariate and multivariate analyses. The minimum sample size based on the Khamis and Kepler (2010) formula, 20+5k, was calculated as 40. Following a more stringent approach, with the a-priori effect size of 15 and 0.8 as the power, the sample size was calculated as 84 (Soper, 2022). Based on these two analyses, the sample size was determined to be acceptable and the study variables were examined in terms of their suitability for regression analyses. Since the hierarchical regression analysis is sensitive to the skewness of the dependent variables (Tabachnick and Fidell, 2019), extreme caution was taken when applying the statistically sound normality and accuracy criteria. The SPSS diagnostic tools revealed no outliers or unusual cases. Therefore, all 99 cases were included in the subsequent analyses. The scores representing the variables to be entered into the regression analyses were found to be distributed normally. In this manner, the dependent variables of the analyses, EAD: 25s, 50s, 75s apnea AA and EAD: 25s, 50s, 75s apnea AI is follows: 25s EAD in AA (skewness = 0.648; kurtosis = 1,846), 50s EAD in AA (skewness = -0,425; kurtosis = 0,796), 75s EAD in AA (skewness = 0,924; kurtosis = 1,213), 25s EAD in AI (skewness = 0,813; kurtosis = 1,617), 50s EAD in AI (skewness = 0,555; kurtosis = 0,774), 75s EAD in AI (skewness = 1,189; kurtosis = 0,925) were all within the acceptable range. The Levene's tests showed that the assumption of homogeneity was met for all of the variables ($p > 0.05$). In addition, the Box's test of equality of covariance indicated the homogeneity of the variance, (Box's M= 60,75, p= 0.90). The bivariate correlations across the study groups showed no multicolinearity. Table 3 displays the bivariate correlations among the study variables. The analyses were conducted using the SPSS.21 statistical package and, due to the small sample size, the Bonferroni adjustment was applied.

Table 1

Means and Standard Deviations of the Variables Used in the Analyses

	AA (N = 11)			**AI (N = 11)**		
	25s	**50s**	**75s**	**25s**	**50s**	**75s**
	M *SD*	M *SD*	M *SD*	M *SD*	M *SD*	M *SD*
EAD	28.16	57.00	83.50	30.47	58.69	80.16
	2.91	*8.51*	*8.53*	*3.89*	*3.20*	*10.06*
EAD (Err.)	16.65	13.99	11.33	23.30	18.71	6.23
	11,65	*12,02*	*11,37*	*13,54*	*6,40*	*11,41*
HR-B	12.78	12.84	13.17	12.44	11.94	12.60
	1.60	*1.40*	*2.41*	*1.26*	*0.88*	*1.74*
HR-IAA	12.67	13.26	13.59	12.41	12.31	13.31
	1.43	*1.27*	*2.45*	*1.09*	*0.76*	*1.32*
HR-AR	12.36	12.71	12.90	12.49	11.74	12.39
	1.46	*1.24*	*2.49*	*1.22*	*0.84*	*1.37*
Stroop I (d)	6.92	4.20	2.94	3.97	2.84	2.95
	4.02	*2.50*	*1.53*	*2.02*	*1.76*	*1.81*
Stroop I (e)	0.00	0.10	0.00	-0.11	-0.11	0.22
	0.00	*0.32*	*0.00*	*0.60*	*0.33*	*0.83*
PANAS PA	35.10	32.10	28.67	30.89	31.11	27.67
	5.69	*7.11*	*5.63*	*9.60*	*9.36*	*10.82*
PANAS NA	15.50	13.70	17.11	15.67	13.67	15.00
	3.41	*3.77*	*5.97*	*5.63*	*4.00*	*6.80*

Note. AA= apnea in the air; AI= apnea immersed; HR= heart rate; EAD= estimation of apnea duration; EAD (Err.)= directional error of EAD; B= baseline; IAA= immediately after apnea; AR= after rest; s= seconds; Stroop I (d)= Stroop Interference difference score; Stroop I (e)= Stroop Interference error score; PANAS PA= Positive affect; PANAS NA= Negative affect.

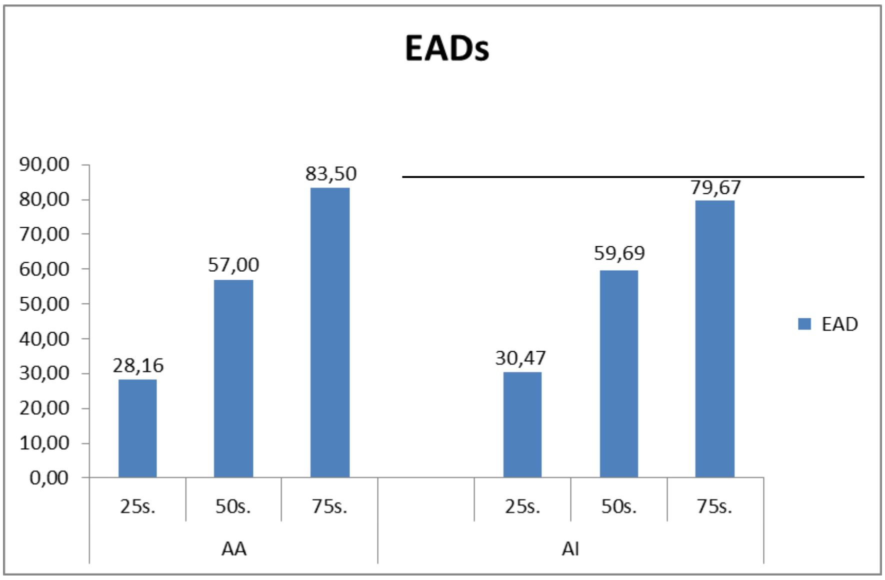
RESULTS

EADs: In order to determine the significant differences between EADs in two modalities, three paired-sample *t*-test analyses were conducted. The results show that the only significant difference is between the EADs of 75s. The 75s EAD in AI (M= 79.67, SD=10.20) is significantly shorter than the 75s EAD in AA (M= 83.50, SD= 9.04, $t(10)$= 2.86, p =

0.024). The EAD of 25s in AA and AI (*t*(10) = -1.42, *p* = 0.197) and 50s in AA and AI (*t*(10)= 0.29, *p*= 0.775) were not significantly different from each other (Figure 2 presents the mean values of EADs).

Figure 2

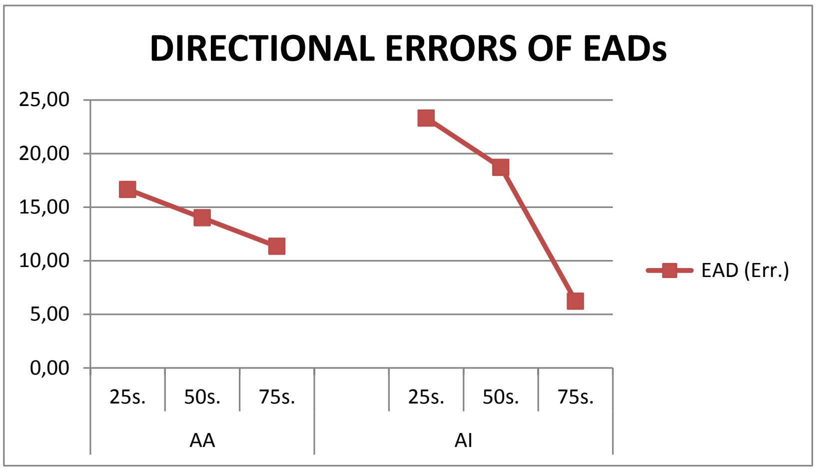
EADs in Apnea in the Air and Apnea Immersed Conditions



Note. AA= apnea in the air; AI= apnea immersed; EAD= estimation of apnea duration; s.= seconds.

Figure 3

Directional Errors of EAD in 25, 50 and 75s in AA and AI Modalities



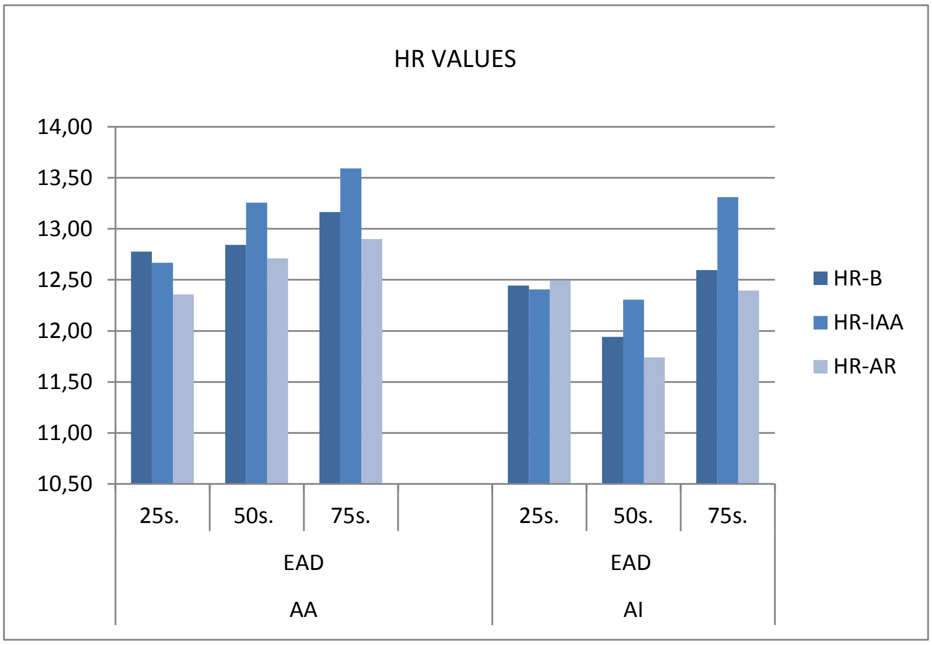
Note. AA= apnea in the air; AI= apnea immersed; EAD= estimation of apnea duration; EAD (Err.)= directional error of EAD; s= seconds.

Although the differences are not statistically significant the EADs in 25s and 50s of EAD in the AA were shorter than the values obtained in the AI. To examine the degree and pattern of underestimation of apnea durations, the directional errors of the EADs were compared by conducting 2x3 within-participants repeated-measures ANOVA (Apnea modality: AA and AI x EAD: 25s, 50s, 75s apnea). The analysis revealed a significant main effect of EAD (*F*(2, 22)= 6.28, *p*= 0.01), but not an apnea modality or interaction effect. Follow-up comparisons showed that EAD errors were significantly lower in 75s of apnea (*M*= 9.12, *SE*= 4.52, *F*(2, 22)= 7.59, *p* = 0.03), compared to 50s (*M*= 19.22, *SE*= 2.18) and 25s (*M*= 17.95, *SE*= 2.57) of apnea. Also *t*-test against 0 (the error free duration estimation) results indicated that the directional error of 75s EAD in the AI modality *(M*= 6.23, *SD*= 11.61) was the only variable that was not significantly different from 0 (*t*= 1.66, *p*= 0.149). This shows that the EAD was most precise during the 75s apnea in the AI. Although the pairwise comparisons did not provide any other statistically significant differences, as Figure 3 shows, there is an observable trend in the accuracy of EADs for 25s and 50s apnea in the AA condition.

HR Changes: In order to see the differences in the three HR values (HR-B, HR-IAA and HR-AR) at three EADs (25s, 50s and 75s of EAD) in AA and AI, 2x3x3 within-participants repeated measures ANOVA was conducted. The results indicated a significant main effect of HR, (*F*(2, 22)= 5.99, *p*= 0.01). Pairwise comparisons showed that the HR-B was significantly higher than the HR-AR, (*F*(2, 22)= 8.04, *p*= 0.03), while post-hoc comparisons revealed a statistically significant difference between the HR-AR values of 50s and 75s apnea conditions in AA and AI modalities (see Figure 4). Paired sample *t*-test results indicated that HR-AR was significantly lower than HR-IAA in 50s EAD, (*t*(10)= 2.41, *p*= 0.04) and 75s EAD, (*t*(10)= 1.95, *p*= 0.05) in the AI condition and 50s EAD, (*t*(10)= 2.70, *p*= 0.02) and 75s EAD, (*t*(10)= 2.80, *p*= 0.02) of AA condition. The HR differences were not significant in 25s EAD of either the AA, (*t*(10)= 1.47, *p*= 0.17) or the AI (*t*(11)= -0.49, *p*= 0.63) condition.

Figure 4

HR Values Obtained in 25s, 50s, and 75s of EADs in AA and AI



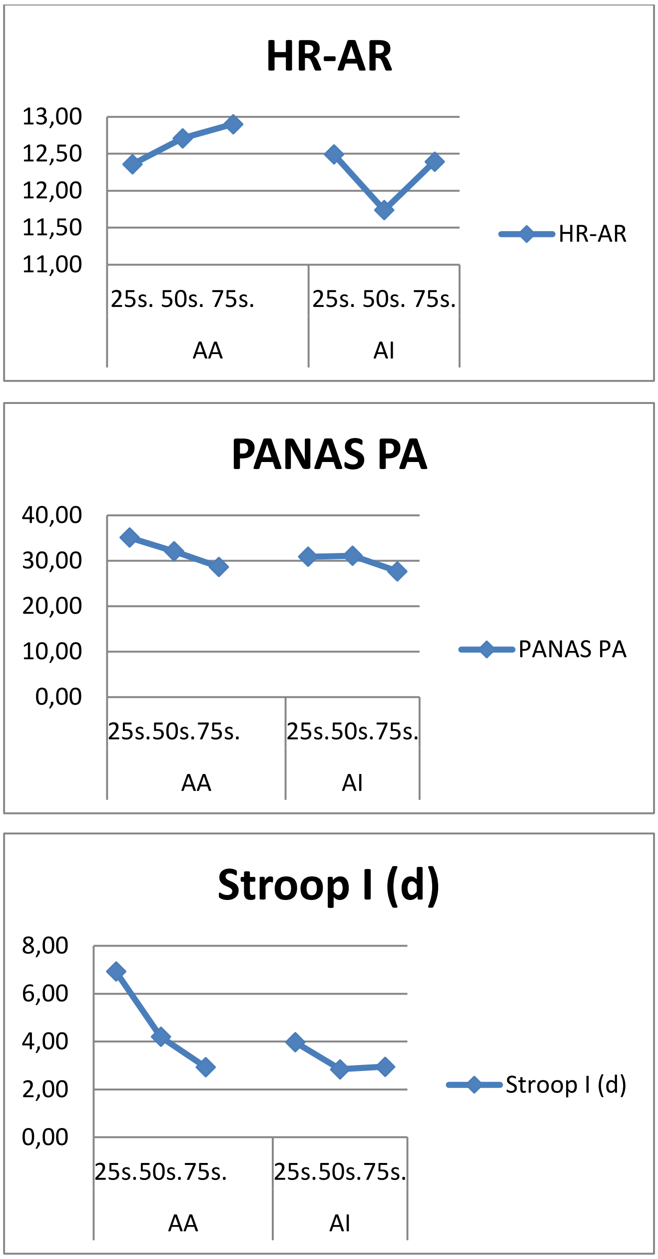
Note. HR-B= Heart Rate-Baseline; HR-IAA= Heart Rate-Immediately After Apnea; HR-AR= Heart Rate-After Rest

As it can be seen in Table 1 and Figure 3, the HR values observed in the AI condition were smaller compared to those in AA. However, these differences did not translate into statistical significance. A series of paired sample *t*-test analyses revealed that only the difference between the HR-AR values of 50s EAD in the AA (*M*= 12.46, *SD*= 1.18) and AI (*M*= 11.54, *SD*= 0.63) approached the statistical significance, (*t*(10)= 2.17, *p*= 0.066).

Stroop Color-Word Interference Test: In order to test the difference in the Stroop Interference duration [Stroop I (d)] scores by modality and EAD., 2x3 within-participants repeated measures ANOVA (Apnea modality: AA and AI x EAD: 25s, 50s, 75s) was conducted. The results indicated a significant main effect of modality (*F*(1, 22)= 12.45, *p*= 0.01) and EAD, (*F*(2, 22)= 38.61, *p*= 0.006). The pairwise comparisons showed that the Stroop I (d) in the AI (*M*= 3.29, *SE*= 0.58) was significantly shorter than AA (*M*= 4.92, *SE*= 0.98), *(F*(1, 22)= 9.14, *p*= 0.02). The mean Stroop I (d) score observed in 25s of EAD (*M* = 5.87, *SE* = 1.21) was significantly higher, (*F*(1, 22)= 3.85, *p*= 0.02) than the scores observed in both 50s (*M* = 3.37, *SE* = 0.75) and 75s EAD (*M*= 3.12, *SE*= 0.58).

Figure 5

(a) HR-AR values; (b) Stroop I (d) scores; (c) PANAS PA scores obtained in 25s, 50s, and 75s of EADs in AA and AI



Note. AA = apnea in the air; AI = apnea immersed; HR-AR = heart rate after rest; s. = seconds. Stroop I (d) = response time to complete the Stroop task; PANAS PA = Positive affect

Affectivity: By conducting 2X3 (AA, AI x 25s, 50s and 75s of EADs) within-participants repeated measures ANOVA, PANAS scores of the participants were compared. For PANAS PA, the EAD main effect was significant, (*F*(2, 22) = 35.03, *p* = 0.00), and pairwise comparisons showed that the PANAS PA score in the 75s of EAD was significantly lower (*M* = 27.07, *SE* = 2.38, 95% CI = 1.51- 3.22) compared to 50s (*M* = 31.28, *SE* = 2.62, 95% CI = 2.35- 6.07) and 25s of EAD (*M* = 32.14, *SE* = 2.10, 95% CI = 2.93- 7.20). PANAS NA scores on the other hand, did not change significantly either by EADs (*F*(2, 22) = 1.28, *p*= 0.31) or by modality (*F*(1, 22) = 0.19, *p* = 0.67).

Hierarchical Multiple Regression Analyses Predicting the Accuracy of EADs: In order to explore the variables predicting the directional errors of EAD, six separate stepwise multiple regression analyses were conducted. In all of these analyses, the directional errors of three EADs in each modality were dependent variables. Based on the findings within the literature and the hypotheses of the current study, three predictor variables were entered in the model: HR-AR, Stroop I (d) score and PANAS PA, respectively. The results of the regression analyses, ΔR^2 and β's are presented in Table 2. The bivariate correlation matrix of the variables used in the analyses is presented in Table 3. Figure 5 shows the mean values of predictor variables across conditions.

Table 2

Hierarchical Multiple Regression Analyses Predicting the Accuracy of EAD from HR, Attention and Positive Affect in AA and AI conditions

	AA						AI					
	25s		50s		75s		25s		50s		75s	
	ΔR^2	β	ΔR^2	B	ΔR^2	β	ΔR^2	B	ΔR^2	β	ΔR^2	B
Step 1	**0.07**		**0.06**		**0.74****		**0.00**		**0.31***		**0.30***	
HR-AR		-0.09		-0.87*		0.89*		0.53		-0.43*		0.69**
Step 2	**0.24**		**0.13**		**0.01**		**0.10**		**0.18**		**0.14**	
Stroop I (d)		-0.50		-0.80*		0.20		0.77		-0.71**		0.79**
Step 3	**0.01**		**0.45***		**0.02**		**0.24**		**0.26***		**0.36***	
PANAS PA		0.12		0.72*		-0.17		0.55		0.59*		0.72**
Total R^2	**0.26**		**0.63***		**0.76****		**0.34**		**0.75****		**0.80****	

Note. AA= apnea in the air; AI= apnea immersed; HR-AR= heart rate after rest; s= seconds. Stroop I (d)= response time to complete the Stroop task; PANAS PA = Positive affect

**p* < .05. ***p* < .001.

Table 3

Correlation among the Variables in the Analysis

	AA								
	25s			**50s**			**75s**		
	HR-AR	Stroop I (d)	PANAS PA	HR-AR	Stroop I (d)	PANAS PA	HR-AR	Stroop I (d)	PANAS PA
EAD (Err.)	0.08	-0.49	0.18	-0.25	-0.06	0.46	0.88**	-0.29	0.41
HR-AR	-	-0.35	-0.06	-	-0.73*	0.24	-	-0.45	0.51
Stroop I (d)		-	-0.10		-	0.02		-	0.15
PANAS PA			-			-			

	AI								
	25s			**50s**			**75s**		
	HR-AR	Stroop I (d)	PANAS PA	HR-AR	Stroop I (d)	PANAS PA	HR-AR	Stroop I (d)	PANAS PA
EAD (Err.)	-0.01	0.24	0.28	-0.56	-0.46	0.32	0.54	0.16	0.41
HR-AR	-	-0.68*	-0.02	-	0.06	-0.14	-	-0.35	0.17
Stroop I (d)		-	-0.33		-	0.47		-	-0.54
PANAS PA			-			-			

Note. AA = apnea in the air; AI = apnea immersed; EAD (Err.) = directional error of EAD; HR-AR = heart rate after rest; s. = seconds. Stroop I (d) = response time to complete the Stroop task; PANAS PA = Positive affect
*$p < 0.05$. **$p < 0.001$.

The results of hierarchical regression analysis conducted separately for each of the dependent variables showed that, the predicted model was not significant in 25s of EAD in AA or AI. However, for the 50s of EAD in the AA condition, three variables predicted 63% of the total variance and all of them were significant. The same pattern of relationship was observed for the 50s of EAD in the AI condition, where 75% of the total variance was explained by three variables. For 75s of EAD in the AA condition, three variables explained 76% of the total variance, and the only significant variable was the HR-AR. Finally, for 75s of EAD in the AI condition 80% of the total variance was explained by three variables, all of which were significant.

DISCUSSION

This study provided experimental evidence for the role of affectivity and attention, in conjunction with HR, on the long durations of TE based on our proposed model that both bottom-up and top-down variables are involved in the TE. In accordance with the AGM, the results of the current study supported our main premise concerning top-down control of bottom-up factors in TE. In addition to the HR, which is considered to be the pacemaker in the internal clock system, positive affect and attentional capacity of the participants contributed to the accuracy of the TE in long durations. Since it is known that "perception and estimation of durations less than about 3s involves very different processes than of longer durations" (Block et al., 2010, p., 334), this study contributes to the current TE literature by providing experimental data regarding the accurate estimation of target durations of 25s, 50s and 75s. Out of the three main hypotheses tested in the current study that were tested, the first one (Both the duration and the modality of apnea influence the HR) was partially supported: As predicted, the HR values that were obtained during the AI are smaller compared to the ones in the AA. However, contrary to our prediction, the HR values in 50s and 75s of EADs are not smaller compared to 25s of EAD. Specifically, our HR measures showed that while in the AA condition all three types of HRs- HR-B, HR-IAA and HR-AR- heightened by the increase in the target EADs, in the AI condition all HR values showed a decline in 50s compared to 25s and 75s of EADs. As we expected, in all of the EADs in both AA and AI conditions, the HR-AR values were lower compared to those of HR-B. The second hypothesis of the current study (The estimation of durations in apnea in the air is shorter compared to apnea in immersion) was also partly confirmed. As predicted, the EADs in the AA are shorter compared to the ones in the AI, but only for 25s and 50s EADs, and not for 75s EAD.

Contrary to our expectations, the third hypothesis was not confirmed: we hypothesized that, for short intervals (25s) attention and affectivity predict the accuracy of the TE. The results of the stepwise hierarchical regression analyses showed that for 25s EAD, none of the predictor variables were significant. Similarly, it was hypothesized that for longer intervals (50s and 75s) HR predicts the accuracy of the time estimation. Against our expectations, for 50s of EAD in the AA, positive affect; for the 75s of EAD in the AA, HR; for the 50s and 75s of EADs in the AI, all three variables were significant predictors of the accuracy of TEs.

Based on the repeated measure ANOVAs and stepwise hierarchical regression analyses, the cardinal finding of this study is that HR alone is not the only factor influencing time estimation in long intervals. Second, attentional capacity and positive affect contribute to the accuracy of time estimation in a non-constant fashion. Third, these three variables affect the accuracy of TE differently according to the modality and the duration of the target interval. Forth, surprisingly, the participants were most accurate in estimating the time during 75s of EAD in the AI condition. In proposing a possible explanation for these findings, we discuss the results of ANOVAs and regression analyses separately.

EADs: Regardless of the apnea conditions, all three target intervals were underestimated, which is consistent with the extant prospective time estimation literature (Block and Zakay, 1997; Block et al., 2010) where long exposure durations were underestimated (Bar-Haim et al., 2010) compared to shorter intervals. In the current study, overall, the magnitude of the underestimation (directional errors of EADs) decreases as the time to be estimated increases, leading to longer durations to be less underestimated than shorter durations (25s vs. 75s). However, when the EADs in AA and in AI are compared, it is seen that for the 25s and 50s of EADs, the participants were more accurate in the AA condition (see Fig. 3). Surprisingly, the EAD of 75s in the AI has the lowest error value, or to state it another way - the most accurate time estimation. When we examined the values of the other variables obtained for the 75s of EAD in the AI, we see that both the PA and Stroop I (d) scores were also the lowest scores observed in the study. Based on the pattern of HR change *alone*, the most accurate TE can be interpreted as follows: Because a deescalating stimulus tends to be perceived longer while an accelerating stimulus tends to be shorter (Matthews and Meck, 2014), the participants in the current study might have encoded the HR data as a stimulus and, hence, estimated the time elapsed during the apnea by perceiving the change in their HR. The HR data in the AA shows that it accelerates as the target durations increase and errors in EADs decrease as the target durations increase. Therefore, as the HR increases, the time is perceived shorter, leading to a decrease in the underestimation of the elapsed time. By the same token, in the 75s of EAD of the AI, as the HR increases the participants encode this as an escalating stimulus and tend to overestimate the elapsed time, bringing about more accurate TE.

HR: HR analysis showed that the HRs before the apnea were higher compared to the HR after 3min of rest in 50s and 75s apnea conditions. This result indicated the clear effect of apnea in the reduction of heart rate in both AA and AI. The decrease in the HR values in the 25s and 50s of the AI condition was significantly more pronounced, showing the effect of diving reflex. It is known that direct contact with water specially when the person is immersed (forehead, eyes and nose in the water) elicits a diving response (Andersson et al., 2004; Caspers et al., 2011; Foster and Sheel, 2005). The difference between HR-IAA and HR-AR suggests a profound decrease in HR in 50s and 75s apnea condition. The significantly higher HR-AR in the 75s of apnea condition compared to 50s shows a partial recovery of the HR in in the former apnea condition. This finding is consistent with Andersson et al.'s findings (2002), where the researchers observed an increase in the HR at around 75s of apnea. The result of the present study is also consistent with the findings of Heusser et al., (2010) and Lindholm et al., (2006), where the cardiac output showed a fast reduction within the first minute (around 50s) and recovered partially (around 75s). The absence of a statistically significant difference between the HR values of 25s apnea in AA and AI modalities was also as expected. Previous research reported that the minimum HR is obtained at around 43s. to 50s of apnea (Caspers et al., 2011). This result shows that 25s apnea is not long enough to produce bradycardia, and that a minimum HR can be observed in 50s apnea in the AI condition.

One unexpected finding of the HR data obtained in the current study is the possible influence of foreknowledge of the time to be estimated on the HR. The similarity of the pattern of change that was observed in this study in the HR-B, HR-IAA and HR-AR in both AA and the AI conditions suggest that such foreknowledge affects the HRs. The pattern of change in the HR-IAA and HR-AR which are caused by the apnea was also observed in the HR-B values, which were measured before the apnea performances. More interestingly, a marked decrease that was expected for the HR-AR in the AI due to the diving reflex was also observed in the HR-B values. The results suggested that, despite the absence of full immersion (heads out), the HR values started to decrease before the participants start to perform the apnea in the AI condition (see Figure 4). This might indicate that free-divers' anticipatory bradycardia is triggered by their body's contact with the water without necessarily being fully immersed. When we consider the fact that diving reflex is controlled by complex neural network integrating respiratory and cardiovascular systems (Foster and Sheel, 2005), this result might add another perspective to the mechanisms of diving reflex. From a metacognitive point of view, one can argue that prior knowledge about the duration and the modality of the apnea alarms the body in such a way that the HR starts to change based on this knowledge before the apnea performance. From our integrative point of view, the baseline HR levels of the participants - which were measured before the apnea task and not caused by the apnea induced bradycardia - change according to both modality and the target EAD, thus supporting the idea that bottom-up factor(s) are under the influence of top-down factors in the TE process. This can be considered as a support for the existing literature regarding the interdependence between these two processes (Hughes et al., 2013; Hutchison, 2011).

Attention: The results that obtained regarding attentional control show that, overall, the participants are more attentive or concentrated in the AI condition and in the longer EADs compared to the AA and shorter EAD's. By keeping in mind the effect of foreknowing the EAD task in prospective paradigm, one way to interpret this result is to assume that the decrease in the Stroop I (d) scores indicate greater task engagement. Here, the view that we take in terms of the indication of the Stroop performance is similar to Halin et al. (2014): ‘degree of concentration applied to focal task’ in estimating the target interval as accurately as possible. The results of the current study suggest that the participants might have concentrated more on the EAD tasks that are relatively more challenging, which are longer apnea durations and immersed apnea.

However, in terms of the attentional control-TE accuracy relationship, this study produces conflicting results for the AA and AI conditions. In the AA, in line with the related literature, the reduction in the directional error scores of EADs were observed as the participants’ Stroop I (d) scores decreased. Lessened attentional resources lead to an underestimation of the actual time interval (Bi et al., 2013). However, in the AI condition although the Stroop performance was better for the 25s and 50s of EADs, the directional errors were higher compared to the ones in the AA. This difference, that is, worse TE accuracy despite better attentional control in the 25s and 50s in the AI, can be explained by Brown’s review of 80 experiments (1997) which shows that increased task demands disrupt timing, causing perceived time to shorten. However, this account does not apply to the TE accuracy in the 75s in the AI, which is supposedly the most challenging task in the current study. Our findings regarding the Stroop performance of the participants are in line with Hutchison’s (2011) Stroop performance findings, which indicate, if engaged, proactive control involves the maintenance of task goals over trials and decreases the interference. One can argue that, in the AI condition, conducting the EAD in the water is an additional load and this may cause dual-task interference. It should be noted that the duration judgment is affected by the paradigm used. A meta-analytical review of the subject show that in the prospective paradigm that we have used in the current study, relative variability in the TE increases with cognitive load (Block et al., 2010). However, our results which indicate a better attentional control and TE accuracy in longer EADs are in line with Healy et al.’s (2005) proposal of ‘functional task principle’, which means that the timing and the non-temporal tasks are combined and performed as a single task; therefore, prospective timing is not a dual-task condition. Finally, the difference in the Stroop performance of the participants in the AA and AI condition is not likely due to the modality difference. Although Block et al.’s (2010) review clearly indicates the absence of modality effect, in the current study the modality difference might be more of a cognitive difference, leading the participants to engage less in the EAD tasks in 25s and 50s of EAD. One can assume that holding the breath underwater for 25s and 50s of apnea for the participants is an easy task and with lower survival value compared to 75s of apnea, therefore, although their attentional capacity is high, they do not engage in the task.

Affectivity: Positive affectivity (PA) was found to vary by both the modality and the EAD duration. Overall, the PA scores in the AI were lower compared to AA condition. The PA also decreased as the target interval to be estimated increased. In 75s of EAD in the AI, the PA score was recorded as its lowest. Our results indicate that the participants estimated the elapsed time shorter when their PA scores are high. As their PA scores decreased, so did their directional errors of EADs, suggesting a decline in the rate of underestimation. It is important to note, however, that in the current study, the TE accuracy did not show any significant difference in the negative affectivity scores of the participants. Therefore, ‘depressive realism’ - negative moods’ bolstering effect on systematic processing of information - (Allan et al., 2007), does not seem to be involved in the TE process. In the current study, the association between accurate TE and decrease in PA is consistent with the literature regarding the relationship between mood and cognition. Blanchette and Richards (2010) showed positive mood depleting cognitive resources, leading to a decline in the motivation to systematically process the message or reduce message scrutiny.

Secondly, based on the same premise that TE involves complex information processing, the participants might have considered the risks associated with the experimental tasks. The short durations of EADs, such as 25s and 50s in the AA condition, pose no significant risk to free-diving athletes subject to this research. From this perspective, the results of our study are consistent with the risk-aversion literature. Isen and colleagues showed that, when the level of risk increases (Isen et al. 1988) and the situation is self-relevant (Isen and Patrick, 1983), the positive mood participants become more risk-aversive than control group.

Predictors of EAD Accuracy: The results of hierarchical regression analyses supported our view of integration of top-down and bottom-up factors in TE. When the HR, affectivity and attention variables are considered together, results suggest that the pattern of the change in the accuracy of long duration estimation seems to be affected by both the modality and the duration of the apnea tasks differently. Therefore, we conclude that prospective judgments on long intervals depend on both the attention allocation policy of the executive system (e.g., Zakay, 1993) and the arousal level (e.g., Zakay et al., 1983). The task duration knowledge which is an important variable that affects the accuracy of TE (Tobin and Grondin, 2012), might have further influenced the focusability of the participants. Because, by definition, concentration involves such control of external as well as internal factors, even though the nature of the bottom-up factor (HR) is identical, two top-down cognitive factors: attention and affectivity seem to influence the TE accuracy (Hughes et al., 2013). The present study suggests that free-divers can have their unique safeguarding strategies when they are committed to time relevant tasks, and that attention and affectivity variables are as important as HR data in their accurate estimation of time.

Implications for Practice: Accurate time estimation by free-diving athletes has a critical role for their safety. The results of this study indicate that the HR data alone may not be sufficient for accurate TE. The athletes' affectivity and attentional level also determine the TE accuracy to a remarkable extent. For their safe performance, they need to consider affectivity and attentional level during competitions. While training, coaches or trainers need to devise methods to monitor athlete's affectivity levels and concentration as well as apnea performance. If deemed necessary, psychologist needs to be involved in the training of the professional free-diving athletes to help the attention and affect regulation of the free-divers. Future studies are required to examine how long intervals such as the ones that were examined in the current study are estimated in retrospective paradigms. The effect of the pattern of the heart rate change during the apnea performance on the TE needs to be examined in detail where the continuous HR data are collected throughout the apnea performances.

Author Contribution: Both authors equally contributed to the all aspects of this research**:**

1. **Neşe ALKAN:** Idea-concept development, Design, Implementation, Data collection and processing, Data analyses, Article writing, Critical review-editing
2. **Tolga AKIŞ:** Idea-concept development, Design, Implementation, Data collection and processing, Data analyses, Article writing, Critical review-editing

Information regarding Institutional Review Ethical Board Permission

Review Board Name: Atılım University, Scientific Research Project Board

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Number: B.30.2.ATL.00.02.32.06/10

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