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Effects of Rhythm on the Perception of Urgency and
Irritation in Auditory Signals

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Abstract

This study was devoted to measuring effects of rhythm on the perception of urgency and irritation using temporal perceptual accents to increase the level of rhythm. Two tests have been carried out. The first test measured absolute perception of urgency and irritation. The second test measured relative perception of urgency and irritation. The results of the first test showed how rhythms with fewer accents were perceived more urgent as well as more irritating. However, the results of the second test showed that the odds were lowest that rhythms with zero accents were perceived more urgent as well as more irritating. An explanation that is suggested is that auditory context could play an important role in perceiving rhythm in auditory signals.

Effects of Rhythm on the Perception of Urgency and Irritation in Auditory Signals

Auditory signals are omnipresent in our daily lives. Nowadays, almost every electronic device we buy has one or more. Important properties of auditory signals are that they are transitory; several variables can simultaneously be presented; they can be observed from any location; they cannot be blocked; and everyone can hear them (Lehto, Lesh, & Horrey, 2009). Not all auditory signals are equally important. The message is dependent upon the purpose of the signal and the context within which the signal is presented. For example, a distinction could be made between feedback, warning, and alarm functions. Feedback signals give status information; Warning signals indicate possible danger, problems or unpleasant situations; Alarm signals indicate acute danger. These auditory signals do not have to differ by definition. The same signal can be used in different situations. The same sound could be used in one situation as a feedback signal and in another situation as a warning or even an alarm signal. The source of the signal (e.g. microwave or heart rate monitor) and the context in which the signal is presented (e.g. kitchen or intensive care unit) will help to attribute meaning to the sound by means of top-down processing (Van Egmond, 2008).

On the other hand, a considerable amount of evidence is showing how to construct alarm sounds which are reliably different in their urgency and where the urgency order can be predicted (Edworthy & Hellier, 2006). The advantage of this urgency mapping is that even if the listener does not know the function of the signal, the urgency can be inferred through the more abstract structural aspects of the signal by means of bottom-up processing (Edworthy & Hellier, 2006; Van Egmond, 2008). Knowledge about urgency perception of different auditory signals is applicable to many situations, particularly in situations where several warning signals must be interpreted simultaneously. In previous literature intensive care units

and audio displays used in complex vehicles such as helicopters have been discussed (e.g. Edworthy, Hellier, & Hards, 1995; Edworthy, Loxley, & Dennis, 1991; Van Egmond, 2008). However, a well-documented problem in workspaces with many auditory signals present is that people consider them to be very irritating. The warning sounds become a distraction (Suied, Susini, & McAdams, 2008; Van Egmond, 2008) and are sometimes even being turned off (e.g. Edworthy, 1994a; Edworthy, 1994b; Edworthy & Hellier, 2006; Edworthy, et al., 1991; Van Egmond, 2008). Depending on the exact function of the signal it should be perceived urgent but not annoying. Taking this problem into account, the question still stands how to attribute meaning to a signal if there is no source or context provided.

Previous research on attribution of meaning to auditory signals has mainly been directed to the effect of specific parameters of auditory signals on the perception of urgency. According to Edworthy (1994a) it is essential to have insight into what makes an auditory signal sound urgent. Most previous studies describe a number of parameters of auditory signals. These can be divided into acoustic parameters (e.g. loudness), spectral parameters (e.g. frequency, pitch, harmony, melodic structure) and temporal parameters (e.g. rhythm, speed, shape of the amplitude envelope, duration of the pulse) (e.g. Edworthy, et al., 1995; Edworthy, et al., 1991; Guillaume, Pellieux, Chastres, & Drake, 2003; Klorman & Bentsen, 1975; Suied, et al., 2008). The more dimensions available to us for discrimination, the more able we are to differentiate between signals (Edworthy & Hellier, 2006). Although rhythm is one of those dimensions, an understanding of the meaning attributed to rhythm in auditory signals seems to be lacking in previous literature. Rhythm is one of the key factors in our ability to discriminate between alarms (Edworthy & Hellier, 2006). Sounds that are different in other ways but share the same rhythm are easily confused. Consequently rhythm is an essential part of auditory signals and its effect on the perception of urgency should be

investigated further.

However, in previous literature on temporal parameters focus has predominantly been on speed and duration of the signal. Only few studies have investigated the influence of rhythm on the perceived urgency of signals. Edworthy, et al. (1995) discussed the impact of change of rhythm in the attribution of meaning to auditory signals, but they did not elaborate on this matter in more detail than changing the duration of the equal pauses between beeps. According to Loxley (1992, in Edworthy, et al., 1995) rhythmic changes improve distinctness and visibility of auditory signals. Suied et al. (2008) investigated the effect of irregular rhythms. Participants listening to these rhythms became less distracted, but there was no difference measured in perceived urgency. Performing research on multiple auditory signal parameters Edworthy, et al. (1991) indicated that syncopated rhythms could be considered slightly less urgent than regular rhythms. The current study will be devoted to contribute to the literature by researching the effects of rhythm on the perception of urgency.

Past studies have not answered the question of the effects of rhythm on the perception of urgency. This study will therefore use other methods. A plausible way to appoint different levels of rhythm was proposed by Povel and Essens (1985). They studied the perception and internal representation of temporal patterns (e.g. Essens & Povel, 1985; Povel, 1984; Povel & Essens, 1985). According to Povel and Essens (1985) temporal patterns in auditory signals are processed by means of an internal clock. This clock symbolizes a mental representation of temporal patterns. The selection of this internal clock would mainly be determined by the occurrence of temporal perceptual accents in rhythms. The perception of accents is usually associated with tones that are louder, longer, or deviating in pitch (Thomassen, 1982, in Povel & Essens, 1985). In sequences of identical tones it might be assumed that no accents would be perceived. However, in sequences of identical tones the following tones become

perceptually marked: relatively isolated tones, the second tone of a cluster of two tones, and the initial and final tones of a cluster of three or more tones (Povel & Okkerman, in Povel & Essens, 1985). Povel and Essens (1985) used these accents to produce rhythms and tested the effect of the internal clock on reproduction of the rhythms. Following studies using these temporal perceptual accents mainly focus on the perception of complexity of various rhythms (e.g. Shmulevich & Povel, 2000; Thul & Thoussaint, 2008). Performing the current study we will measure the effect of rhythm on the perception of urgency by increasing the number of temporal perceptual accents in rhythms.

In this study the following question is raised: what is the effect of rhythm on the perception of urgency in auditory signals? The problem of irritation mentioned earlier will be taken into account, as well as the importance of context. Corresponding to results from Edworthy, et al. (1991), we hypothesize that rhythms with more accents are perceived less urgent than rhythms with fewer accents. Considering urgent sounds to be irritating, we hypothesize that rhythms with more accents are perceived less irritating than rhythms with fewer accents. Two tests will be performed to investigate these hypotheses. The first test will measure the effect of rhythm on absolute perception of urgency and perception of irritation. The second test will take the context of signals into account and measure the effect of rhythm on relative perception of urgency and perception of irritation. In order to investigate these effects of rhythm on the perception of urgency and the perception of irritation we use 20 rhythms with an increasing number of temporal perceptual accents.

Method

An experimental within subjects design was used in this study. All participants went through all of the conditions. The dependent variables were perception of urgency and perception of irritation. The independent variable was rhythm, consisting of 4 levels (0, 2, 3,

or 4 temporal perceptual accents).

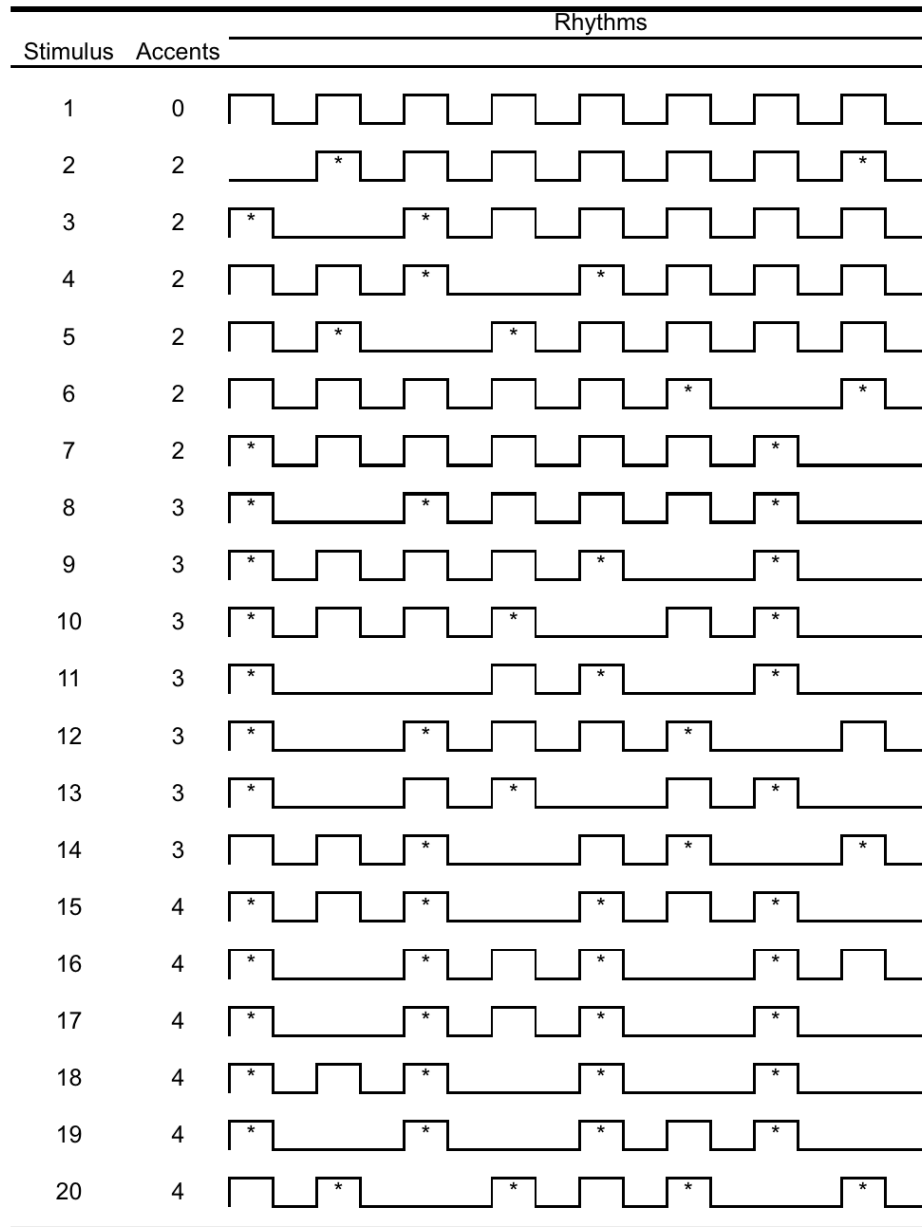


Figure 1. Visual representations of the twenty different rhythms varying in number of temporal perceptual accents (1 rhythm of 0 accents, 6 rhythms of 2 accents, 7 rhythms of 3 accents and 6 rhythms of 4 accents). Protuberances up are tones. Every tone is the same sound with the same length. Notes marked with a ‘ * ’ represent perceptual marked tones and are perceived as accents.

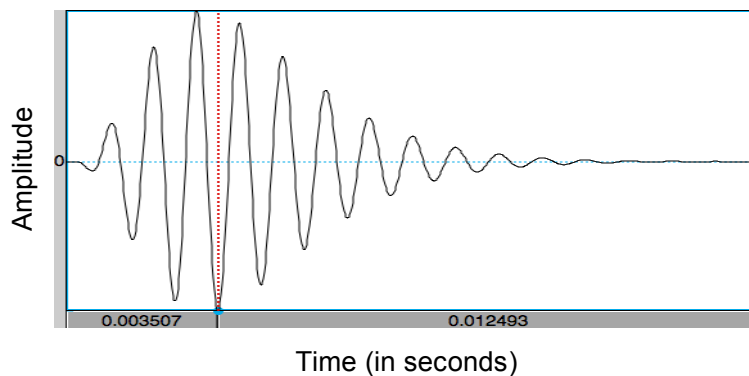


Figure 2. Sound wave of the sound used for the rhythms in this experiment. The total duration of the sound is 16 ms. The sound had an attack of 3.5 ms.

Participants

24 Participants, of which 13 male ($M_{\text{age}} = 30.2$, $SD_{\text{age}} = 9.9$) and 11 female ($M_{\text{age}} = 32.5$, $SD_{\text{age}} = 18.7$) participated in this experiment. Participants came from a wide variety of backgrounds.

Stimuli and apparatus

The stimuli were twenty different rhythms (Figure 1), composed to approach the rhythm of auditory signals. In order to increase the perceived urgency and irritation, rhythm was increased by using four levels of temporal perceptual accents. Relatively isolated tones, the second tone of a cluster of two tones, and the initial and final tones of a cluster of three or more tones are perceptually marked and are perceived as accents (Povel & Okkerman, in Povel & Essens, 1985). As showed in Figure 1, not all levels of rhythm have the same number of stimuli. The main rationale for the unequal number of stimuli is that there is only one rhythm of zero accents (see stimulus 1, Figure 1), but many variations are possible for the other levels of rhythm. Therefore we have chosen to use multiple stimuli for those levels. Different rhythms can have the same amount of accents but have a different feel, because of

the placing of the accents (Povel & Essens, 1985). By using multiple stimuli per level of accents we attempt to control the individual differences between these stimuli.

All rhythms were programmed as a series of the same 1000 Hz sound. This sound was created using computer software program 'Praat' (Boersma & Weenink, 2010). Figure 2 shows the sound wave of the sound used for the stimuli in this experiment. The total duration of the sound is 16 ms. The sound had an attack of 3.5 ms. The stimuli were programmed and recorded at half notes on 120 beats per minute in computer software 'GarageBand 09'. The stimuli, each programmed to be played twice, consisted of two eight-beat bars with a total duration of four seconds. The stimuli were presented on a Beyer Dynamic closed headphone (model DT770 PRO) at a comfortable listening level. The experiment was created using computer software program 'E-Prime'.

Procedure

Two tests were performed. The first test explicitly asked participants to which degree they found the stimuli urgent and irritating. The second test was conducted to measure relative perception of the stimuli. Both tests were preceded by four practice trials. Participants first read a short introduction. The first test consisted of forty trials: twenty trials asking for the perceived urgency regarding the auditory signal and twenty trials asking how irritating the signal was to them on a scale from 1 to 7 (1 = not urgent or irritating, 7 = very urgent or irritating). The trials were presented randomly to control the effect of history and maintain internal validity. The first test was followed by the second test. The second test was a two alternative forced choice test (2AFC) consisting of the same twenty stimuli, now being played in pairs. All stimuli were played once as first sound and once as second sound. These pairs were also presented randomly to control the effect of history and maintain internal validity. Participants had to choose which sound was more urgent to them, the first or the last

signal, using the z-button representing the first and the m-button representing the second signal. The same procedure was followed with the question which signal was more irritating. This resulted in another forty trials. The total duration of the experiment was about twenty minutes.

Analysis

With the first test absolute perceptions of urgency and of irritation were measured. The data was presented on a 7-point Likert scale. In order to analyze this output two separate repeated measures analyses with contrasts between the four levels of rhythm were performed on the mean scores of the participants with on the one hand perception of urgency and on the other perception of irritation as the dependent variables.

The second test measured the participants' relative perception of urgency and irritation of the stimuli. The output of this test was presented on a nominal scale. The relative win and lose frequencies of the different levels of rhythm were computed. With this data goodness of fit chi-square tests were performed to measure significance. Logistic regressions were performed to be able to see the significance of the different levels of rhythm on the perception of urgency and irritation. Finally, the odds were computed that the different levels of rhythm are perceived more urgent or irritating than other rhythms.

Results

Figure 3 and Figure 4 show the results from the first test. Figure 3 shows how rhythms with zero accents are perceived the most urgent and rhythms with three accents are perceived the least urgent. Figure 4 shows how rhythms with zero accents are perceived the most irritating and rhythms with three and four accents are perceived the least urgent.

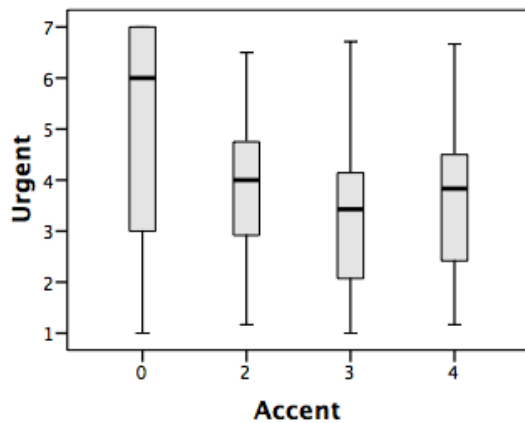


Figure 3. The effect of rhythm on the perception of urgency (1 = not urgent, 7 = very urgent) in rhythms varying from 0 to 4 temporal perceptual accents. The bold line is the median; The boxes represent the middle 50% of the data sample; The area between the boxes and the whiskers contain the other 50% of the data sample.

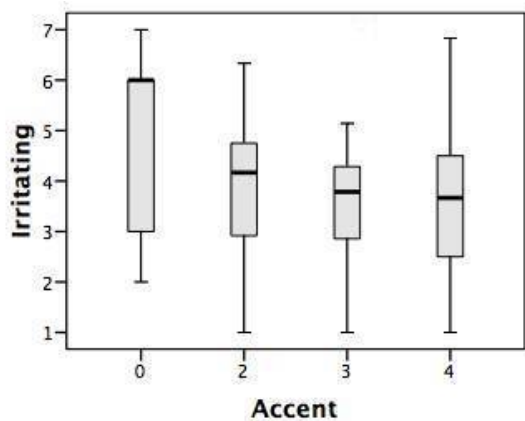


Figure 4. The effect of rhythm on the perception of irritation (1 = not irritating, 7 = very irritating) in rhythms varying from 0 to 4 temporal perceptual accents. The bold line is the median; The boxes represent the middle 50% of the data sample; The area between the boxes and the whiskers contain the other 50% of the data sample.

For the first test repeated measures analyses were performed. The main effect of rhythm on the perception of urgency is significant with $F(3, 69) = 19.85, p < .001, \omega^2 = .14$. The contrasts between the four levels of rhythm were all significant, except for the contrast

between rhythms with two and rhythms with four accents. The main effect of rhythm on the perception of irritation is significant with $F(3, 69) = 9.11, p < .001, \omega^2 = .09$. The contrasts between the four levels of rhythm were all significant except for the contrast between rhythms with three and rhythms with four accents.

Table 1 and Table 2 show the win percentages of the second test for the different rhythms. Goodness of fit chi-square tests were performed on this data. For the urgent data a $X^2(5) = 38.51, p < .0001$ was found. For the irritating data a $X^2(5) = 17.87, p < .005$ was found.

Table 1

Win percentages for perception of urgency from the 2AFC test. Rows win over columns.

Accents	Urgent			
	0	2	3	4
0		.39	.33	.17
2	.61		.39	.44
3	.67	.61		.66
4	.83	.56	.34	

Table 2

Win percentages for perception of irritation from the 2AFC test. Rows win over columns.

Accents	Irritating			
	0	2	3	4
0		.28	.38	.39
2	.72		.48	.40
3	.63	.53		.53
4	.61	.60	.47	

Table 3 shows the results from a logistic regression performed on the data from the second test. Rao's efficient score statistic represents the significance of each level of rhythm found in the data. The results show how rhythms with three accents were most significant and rhythms with four accents were least significant in perceiving urgency. Regarding the perception of irritation rhythms with zero accents were more significant than other rhythms.

Table 3

Results from a logistic regression presented as Rao's efficient score statistic.

Accent	Urgent	Irritating
0	11.88	6.86
2	6.92	3.35
3	14.22	2.35
4	.35	2.94

Figure 5 and Table 4 show the odds to one that rhythms varying from zero to four accents are perceived more urgent and irritating than other rhythms. Figure 5 and Table 4 both show that the odds are that rhythms with three accents are 1.74 to one to be perceived more urgent than other rhythms. Odds are lowest that rhythms with zero accents are perceived more urgent than other rhythms. This is also the case for the perception of irritation. Contrary to the results of the effect of rhythm on the perception of urgency, the results of the effect of rhythm on the perception of irritation show no significant difference between the perception of rhythms with three and rhythms with four accents.

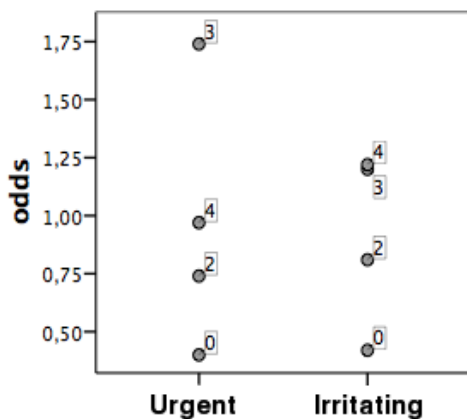


Figure 5: The odds to one that rhythms varying from zero to four accents are perceived more urgent and irritating than other rhythms.

Table 4

The odds to one that rhythms varying from zero to four accents are perceived more urgent and irritating than other rhythms.

Accents	Urgent	Irritating
0	.40	.42
2	.74	.81
3	1.74	1.20
4	.97	1.22

Discussion

The goal of this study has been to gain a better understanding of the effects of rhythm on the attribution of meaning of auditory signals. Hypothesized was that rhythms with more accents are perceived less urgent than rhythms with fewer accents. Considering the problem of irritation, a second hypothesis stated that rhythms with more accents are perceived less irritating.

Two tests were performed to investigate these hypotheses. The results of the first test

supported both hypotheses. The results of the second test on the other hand did not support the hypotheses. The results of the first test show that rhythms with zero accents are perceived more urgent as well as more irritating than rhythms with more accents. This is congruent with the hypotheses. However, the results of the second test are in contrast with the hypotheses as well as with the results of the first test. The odds are lowest that rhythms with zero accents are perceived more urgent as well as more irritating than other rhythms. Previous studies did not have a similar setup and equivalent results have not been found before.

The question why these results occur is of great importance, considering the general importance of having insight into what makes an auditory signal urgent (Edworthy, 1994a; Edworthy, 1994b), the significant role of rhythm in auditory signals (Edworthy, 1994b; Edworthy & Hellier, 2006) and the danger of signals being turned off (e.g. Edworthy, 1994a; Edworthy, 1994b; Edworthy, et al., 1991). In both tests participants were able to differentiate the levels of rhythm. Using the temporal perceptual accents described by Povel and Essens (1985) the current study succeeded in measuring effects of rhythm on the perception of urgency as well as on the perception of irritation. An explanation for finding effects of rhythm could be that the different levels of rhythm had an unequal number of stimuli. The rhythm with zero accents might have attracted attention because it did not occur as often as the other levels of rhythm. Another explanation could be that the rhythm with zero accents sticks out because of its lack of accents. These two explanations could account for the large effect of the zero-level of accent on the dependent variables, but they cannot explain the opposing results of the two tests.

An explanation for these opposing results could be found in the difference between the two tests. In the second test participants had to choose which of two signals they perceived more urgent or more irritating. Therefore, in contrast to the first test the second test

took context of the signals into account. A possible explanation for the opposing results could be that there is a difference between top-down and bottom-up processing of rhythm. This could be part of the process of auditory perception described by Van Egmond (2008). The difference between the two tests of the present study and the process described by Van Egmond is that he states that in order to have top-down sensations a context and attribution of meaning is needed. We now propose the existence of an auditory context. Participants may perceive auditory signals with zero temporal perceptual accents very urgent and irritating when presented without context, and the only way of processing is bottom-up. When presented in relation to another signal, an auditory context is provided that makes top-down processing of the signals possible. Participants now perceive the signals with zero temporal perceptual accents less urgent and irritating than signals with more accents.

The existence of an auditory context would have serious implications for the development of auditory signals, especially signals used in situations in which several warning signals must be interpreted simultaneously, such as in complex vehicles and intensive care units. Not only the physical parameters, the source and the spatial context of the signal contribute to the attribution of meaning, but also the auditory context in which the signal is presented. Other auditory signals might influence, or even alter the message of the signal.

Although more research is needed to gain a more complete understanding of these effects of rhythm on the perception of urgency and irritation, the findings of the current study indicate that there are effects of rhythm on the perception of urgency and irritation. Moreover, the results of this study indicate that auditory context plays an important role in the perception of urgency and irritation of rhythm in auditory signals.

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