7-24-1973

Alternate Monaural Loudness Balance For Tones With Different Duty Cycles

Sharon Ann Dixon

THE UNIVERSITY OF NEW MEXICO
ALBUQUERQUE, NEW MEXICO 87106

Policy on Use of Theses and Dissertations

Unpublished theses and dissertations accepted for master's and doctor's degrees and deposited in the University of New Mexico Library are open to the public for inspection and reference work. *They are to be used only with due regard to the rights of the authors.* The work of other authors should always be given full credit. Avoid quoting in amounts, over and beyond scholarly needs, such as might impair or destroy the property rights and financial benefits of another author.

To afford reasonable safeguards to authors, and consistent with the above principles, anyone quoting from theses and dissertations must observe the following conditions:

1. Direct quotations during the first two years after completion may be made only with the written permission of the author.

2. After a lapse of two years, theses and dissertations may be quoted without specific prior permission in works of original scholarship provided appropriate credit is given in the case of each quotation.

3. Quotations that are complete units in themselves (e.g., complete chapters or sections) in whatever form they may be reproduced and quotations of whatever length presented as primary material for their own sake (as in anthologies or books of readings) ALWAYS require consent of the authors.

4. The quoting author is responsible for determining "fair use" of material he uses.

This thesis/dissertation by Sharon Ann Dixon has been used by the following persons whose signatures attest their acceptance of the above conditions. (A library which borrows this thesis/dissertation for use by its patrons is expected to secure the signature of each user.)

NAME AND ADDRESS	DATE

3/1/73—1M

This thesis, directed and approved by the candidate's committee, has been accepted by the Graduate Committee of The University of New Mexico in partial fulfillment of the requirements for the degree of

MASTER OF ARTS

ALTERNATE MONAURAL LOUDNESS BALANCE

Title

FOR TONES WITH DIFFERENT DUTY CYCLES

Sharon Ann Dixon

Candidate

Communicative Disorders

Department

David T. Benedetti

Dean

July 24, 1973

Date

Committee

Karl W. Hattler

Chairman

Max E. McClellan

William J. Ryan

Richard B. Hood

ALTERNATE MONAURAL LOUDNESS BALANCE FOR TONES WITH DIFFERENT DUTY CYCLES

BY

SHARON ANN DIXON
B.A., University of New Mexico, 1971

THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Arts in Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
December, 1973

ACKNOWLEDGMENTS

The author wishes to acknowledge the patience, encouragement and counsel of Dr. Karl Hattler, the director of this thesis, during its entire preparation.

I wish to thank Dr. Herbert Davis, of the University of New Mexico, Department of Mathematics and Statistics, for his assistance in the preparation of the statistical analysis. I wish to express appreciation for the assistance of Mrs. Alice Luft.

Finally, I wish to thank my parents.

ALTERNATE MONAURAL LOUDNESS BALANCE FOR TONES WITH DIFFERENT DUTY CYCLE

BY

Sharon Ann Dixon

ABSTRACT OF THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Arts in Communicative Disorders
in the Graduate School of
The University of New Mexico
Albuquerque, New Mexico
December, 1973

ALTERNATE MONAURAL LOUDNESS BALANCE FOR TONES WITH DIFFERENT DUTY CYCLES

ABSTRACT

The effect of duty cycle, or the percentage of time a signal is presented, upon the perceived loudness of a pulsed tone was studied utilizing an alternate monaural loudness balance technique. The single ear was employed in an attempt to eliminate any possible artifacts of binaural interaction upon the perceived loudness of pulsed signals.

The factors under investigation included: the difference in duty cycle between a fixed-intensity reference signal and a variable-intensity comparison signal; the use of a relatively high versus a relatively low duty cycle reference signal; and the effect of time after commencement of the loudness balances. Differences in duty cycle between the two tones were set by the experimenter to equal 0, 30, 60 and 80%. Ten normal hearing individuals adjusted the intensity of the 4000-Hz comparison tone to equal the loudness of the fixed-intensity 1000-Hz reference tone over 4-minute trials. The alternate monaural loudness balance technique was employed via the Bekesy audiometer. This pursuit auditory loudness tracking task was a combination of the psychophysical method of limits and the method of adjustment.

The results of the study indicated that loudness, in part, was affected by the signals' duty cycles. During loudness balances with a relatively high duty cycle, the intensity of the comparison signal was continually made more intense as the reference signal was increased in duty cycle, indicating an increased perceived loudness of the reference signal. However, during the loudness balances in which a relatively low duty cycle reference signal was utilized, an opposite duty

cycle-loudness effect occurred. As the duty cycle of the comparison signal was increased, from trial to trial, it was continually made more intense in order to maintain equal loudness with the low duty cycle reference. A significant difference between the three disparate duty cycle conditions was noted within the two experimental reference signal conditions. During the entire experiment, a significant linear growth of response was observed.

The experimental results are in agreement with data from past research concerning the relationship of duty cycle to loudness in which a loudness-memory method and an alternate binaural loudness balance task were utilized.

CONTENTS

CONTENTS – Continued

LIST OF FIGURES

LIST OF TABLES

ABBREVIATIONS AND SYMBOLS

ABLB	alternate binaural loudness balance
AMLB	alternate monaural loudness balance
ANSI	American National Standards Institute
C	comparison tone
cc	cubic centimeter
D	duty cycle difference between the reference and comparison signals
D_{30}	duty cycle difference of 30% between the reference and comparison signals
D_{60}	duty cycle difference of 60% between the reference and comparison signals
D_{80}	duty cycle difference of 80% between the reference and comparison signals
dB	decibel(s)
Hz	Hertz; cycles per second
LOT	lengthened off-time
MCL	most comfortable loudness
msec	millisecond(s)
R	reference tone
$R_H C_L$	relatively high duty cycle reference tone and relatively low duty cycle comparison tone
$R_L C_H$	relatively low duty cycle reference tone and relatively high duty cycle comparison tone
SPL	sound pressure level
t	time point along continuum
TU	transmission units
VU	volume units

ALTERNATE MONAURAL LOUDNESS BALANCE FOR TONES WITH DIFFERENT DUTY CYCLES

CHAPTER I

INTRODUCTION

The perceived loudness of auditory signals is dependent, in part, upon the signals' temporal conditions. Among the data concerning the loudness of on-going sustained or repeated signals, there is growing evidence (5, 6, 8, 17, 18, 25) that loudness perception is strongly influenced by a signal's duty cycle, or the percentage of time the sound is on. Recent data further suggest that the duty cycle influence on loudness progresses slowly over a relatively long time span (8).

Unfortunately, only a few investigations have dealt with the perceived loudness of on-going sustained and repeated signals. Consequently, little is known about the relationship between duty cycle and loudness over extended time spans. Most psycho-acousticians concerned with loudness function have employed signal presentations within short time spans. Thus, loudness judgments are made within discrete time blocks without regard to prior events. Because there has been little research on loudness behavior over extended time periods, the remarkable influence of duty cycle on loudness has gone unrecognized until very recently.

The effects of temporal parameters on loudness judgments extending from 2 to 4 minute time periods have been studied by Hattler (4) and Hattler and Stokinger (8). In the latter study, an alternate binaural loudness balance technique was employed to study the effects of duty cycle upon loudness over a 4-minute period. The duty cycle-loudness relationship has not been investigated using a monaural loudness balance technique in which the influence of binaural interaction is avoided. The present investigation is designed to study the effects of duty cycle upon the perceived loudness of monaurally balanced signals over an extended period of time.

The monaural loudness balance method employs two alternating signals which are presented to one ear. One signal (the reference signal) has a fixed intensity, while the second signal (the comparison signal) is loudness matched by continual adjustment of its physical intensity. The intensity of the comparison signal can be controlled by the subject via the self-recording attenuator of the Bekesy audiometer.

If duty cycle has a measureable effect on the perceived loudness of on-going signals, a tone of specified intensity will be judged louder when it has a high duty cycle and softer when it has a low duty cycle. Using the AMLB technique, the loudness of one tone is compared with the loudness of a second tone of different frequency. If both tones are presented at the same duty cycle, loudness balancing will occur at similar intensities. A difference in duty cycle should yield loudness balances at unequal intensities. If loudness is unefected by duty cycle, conditions of duty cycle equality and disparity will yield identical loudness balance data. An extended period of loudness balancing is employed in order to observe any change in the perceived loudness of auditory signals as a function of time.

Chapter II contains a review of literature which is pertinent to the loudness balance methods used in the experiment. Subsequent chapters of the thesis include a detailed description of the procedures employed and the results obtained from the study. Discussion and conclusions drawn from the investigation are presented last.

CHAPTER II

REVIEW OF LITERATURE

Introduction

Loudness and loudness functions have been the basis of much experimental investigation, even in the very beginnings of psychoacoustic research. Although Fletcher and Munson (3) described the monaural equal loudness contours in 1933, their technique has been put to little use in experimentation dealing with alternate monaural loudness balances (AMLB) and perceived loudness.

The following will include a review of the AMLB technique and the factors involved in the use of the single ear while investigating loudness mechanisms.

Alternate Monaural Loudness Balancing

The comparative loudness of tones with different frequencies was originally observed by Kingsbury (10). Monaural loudness balances were employed whereby signals ranging from 60 to 4000 Hz were loudness matched to a 700-Hz reference set at various sensation levels measured in transmission units (TU). From the resultant data, Kingsbury developed contour lines of equal loudness. These contour lines indicate equal loudness for 1000-Hz and 4000-Hz tones when they are presented at identical SL's.

Fletcher and Munson (3) equated the loudness of diverse frequencies to several sensation levels of a standard reference 1000-Hz signal. The equal-loudness contours, or phon curves, were plotted from the data. With the Fletcher-Munson equal loudness contours, it is apparent that at any phon level the 4000-Hz tone must always have a greater sensation level in order to achieve equal loudness with the 1000-Hz tone. At the 50 phon level, the difference between the two signals is approximately 6 dB.

Reger (16) was the first to propose the specific use of alternate monaural loudness balances as a clinical tool to determine the loudness function of pathological ears. By using the equal loudness contours of Fletcher and Munson as a guide, Reger had patients balance the loudness of tones of two different frequencies when they had normal hearing for one frequency and abnormal hearing for the other frequency in the same ear. The loudness function of the ear was judged from the results of loudness balances between the two frequencies when compared to the equal loudness contours.

Monaural Masking: Backward and Forward Masking

Backward masking produces a unique consequence in which a subsequent stimulus makes less effective a prior stimulation. Forward or residual masking affects a subsequent stimulation and is related to the phenomena of adaptation and sensory fatigue (15).

Samoilova (20) used a monaural technique to study the masking relationship of two tones of adjacent frequencies (e.g. 1000 Hz and 1200 Hz) presented in temporal proximity. The amount of backward masking was especially dependent upon intersignal duration. Nevertheless, there was continual increase in both forward and backward masking as the interstimulus intervals became shorter than 100 msec. Less forward than backward masking was noted throughout; however, the most forward masking was evident with signals above 1000 Hz.

In an earlier study of backward masking by Samoilova (19), a masked signal of 20 msec duration and a 300 msec masker were separated by a 10 msec intersignal duration. For a 1000-Hz maskee, a 4000-Hz masker yielded 15 and 22 dB of backward masking when presented at sensation levels of 60 and 80 dB, respectively. The specific effect of a 1000-Hz masker upon a 4000-Hz signal was not tested; however, the backward masking yielded by a 1000-Hz masker of 60 and 80 dB SL presented in proximity to a 3000-Hz signal was 12 and 23 dB, respectively. The effect of the 1000-Hz masker upon a 6000-Hz signal was approximately 3 and 7 dB. With the 4000-Hz signal as the masker, there was a downward spread of masking (toward the lower frequencies). However, an upward spread of masking was noted with the 1000-Hz tone as the masker.

By the use of the sweep frequency mechanism of the Bekesy audiometer, Ehmer and Ehmer (2) found that a single frequency masking tone yields residual masking of signals close to the frequency of the masker. This "peak frequency" of masking tends to shift to higher frequencies as the masker becomes more intense; however, this "peak" never becomes an harmonic of the masker.

Loudness Adaptation

Mirabella, Taub and Teichner (12) employed a technique in which a 1000-Hz continuous signal, presented monaurally, was varied in intensity by subjects in order to compensate for loudness changes due to adaptation. The intensity of the tone was varied from trial to trial. An adaptation-like phenomenon occurred whenever the intensity of the signal was less than 70-dB SPL. Discrete presentations of the continuous signal at intensities above 70-dB SPL yielded a decrease in the amplitude of the signal with passage of time, indicating the presence of a loudness growth phenomenon.

Stokinger, Cooper, Meissner and Jones (25) have compared the simultaneous dichotic loudness balance with the delayed balance technique as to the amount of adaptation yielded by each method. With the simultaneous dichotic loudness balance technique, two signals were presented at the same time in opposite ears; whereas, in the delayed balance technique the two signals, presented contralaterally, were separated in time. The simultaneous technique yielded little adaptation while the delayed balance results exhibited no adaptation. The adaptation observed was more likely to occur at intensities below 50-dB SPL and at the test frequencies of 250 and 1000 Hz. No adaptation was evident with a 4000-Hz tone as the stimulus. Stokinger, Cooper and Meissner (24) suggested that adaptation which had been measured during previous investigations may have resulted from binaural interaction phenomena and was, perhaps, artifactual in nature. They questioned the occurrence of monaural loudness adaptation in the peripheral auditory system.

Loudness Tracking Methods

Pursuit and compensatory loudness tracking methods have been compared by Pikler and Harris (14). Compensatory tracking requires an individual to maintain a constant loudness level in the face of intensity changes, whereas, during pursuit tracking the subject duplicates loudness changes. Overall, compensatory tracking was found to be slightly more reliable than pursuit tracking. The average momentary tracking error for monotic pursuit tracking was 3.2 dB. Neither compensatory nor pursuit tracking exhibited differences in reliability between their respective monotic and diotic modes of tracking.

Loudness and Duration of a Signal

The on-duration, or amount of time a signal is presented, is known to affect the perceived loudness of a signal. Bekesy (1) noted that a signal of a relatively short on-time has to be increased in intensity in order to have equal loudness with a signal of longer on-time. Miskolczy-Fodor (13) found that the difference limen for the perceived loudness of tones above approximately 10-dB SL did not change when the on-duration was increased beyond 100 msec. The loudness of the signals did vary, however, depending upon the rise-decay times of the signals.

Small, Brandt and Cox (22) employed monaural loudness balances between a noise burst of variable duration and a 500-msec noise burst of the same intensity. For loudness matches in which signals were 60-dB SL, the signal with variable duration did not reach equal loudness with the 500-msec signal until it was 15 msec long. At 35 dB SL the short burst was 30 msec long at the point of equal loudness with the 500-msec signal. As the signals were decreased in intensity, the variable noise burst had to be increasingly longer at the equal loudness points.

In a loudness-tracking study by Hattler (4), subjects maintained the loudness of reference tones of 50- and 80-dB SPL over a 2-minute tracking period. Pulsed tones with on-durations ranging from 40 to 200 msec were made consistently more intense than the continuous signals in order to maintain the reference loudness. For example, a pulsed signal with on-durations of 40 msec and off-durations of 160 msec (duty cycle equals 20%) yielded similar data to a signal with on-durations of 200 msec and off-durations of 800 msec (duty cycle also equals 20%). Thus, loudness differences were not directly attributed to differences of on-duration.

Loudness and Duty Cycle

The effects of duty cycle (or the percentage of time a signal is on) upon loudness have been studied using a loudness memory tracking technique and alternate binaural loudness balances (ABLB). Rintelmann and Carhart (18) had subjects track a recalled loudness and a "most comfortable" loudness (MCL) using both a pulsed (50% duty cycle) and a continuous signal. For both the MCL and recalled loudness, the continuous signals were tracked at lower intensity levels than the pulsed signals. This defined more clearly the phenomenon of the Type V Bekesy Pattern in which continuous signal tracks are recorded at a lower intensity than pulsed signal tracks (9, 17). Hattler (4) employed the recalled loudness tracking technique with signals ranging from 20 to 100% duty cycle. The signals with the lowest duty cycles (20%) were increased in intensity maximally, in order to maintain a constant loudness, suggesting a decrease in loudness as a result of lowering duty cycle. Pulsed signals of 20% duty cycle (40 msec on-time and 160 msec off-time; 200 msec on-time and 800 msec off-time) were loudness tracked at intensity levels from 7.59 to 13.77 dB greater than the continuous (100% duty cycle) signal. Accordingly, as the duty cycles of the signals were increased, the intensity levels of the signals were decreased by the subjects. This decreased loudness perception of signals with 20% duty cycle (200 msec on-time and 800 msec off-time) was also shown by Hattler and Dixon (7) at low sensation levels ranging from 1- to 20-dB.

Using alternate binaural loudness balances, Hattler and Stokinger (8) reported that the effect of duty cycle upon the loudness of an interrupted signal is clearly present, although it is somewhat decreased when loudness memory factors are eliminated.

Comment

The present investigation proposes to further eliminate possible procedural artifacts, specifically the effects of binaural interaction, upon loudness. The following chapter includes a detailed description of the experiment and the instrumentation which was employed.

CHAPTER III

INSTRUMENTATION AND PROCEDURE

Introduction

The present investigation was designed to study the influence of duty cycle on the loudness of monaural tones over extended periods of time. If the loudness of monaural tones is, in part, determined by duty cycle, signals having equal duty cycles will yield equal loudness and signals having unequal duty cycles will yield unequal loudness. Thus, duty cycle conditions will influence the sound pressure levels at which two signals are loudness balanced. Conversely, if duty cycle has no measureable influence on loudness, two signals will be loudness balanced at equal SPL's regardless of their duty cycle conditions. The experiment was designed to determine the influence of three primary factors on monaural loudness balances:

1. Equality vs. disparity of duty cycles.
2. Duty cycle of the reference signal vs. duty cycle of the comparison signal.
3. The amount of time after commencement of tracking.

The AMLB technique was employed in an attempt to avoid binaural interaction effects.

Subjects

The experimental group consisted of 10 audiometrically normal individuals, 6 males and 4 females between the ages of 20 and 32 years, mean age 25.8 years, median age 25.5 years. Normal hearing was defined as monaural sensitivity thresholds no greater than 15 dB

(ANSI 1969 Standard) for each ear at octave intervals between 250 and 8000 Hz. All subjects had a negative history of otologic pathology.

Instrumentation

Acoustical Environment

All training and experimental sessions were conducted in the same acoustically treated test chamber (IAC Model 1201A) which was of double-walled construction with an acoustically damped window. The subject's chamber contained the subject's earphones, a light signal and a response switch, while all other instrumentation was located outside the test chamber.

Ambient-noise levels of the subject's chamber were measured at the approximate locus of the subject's ears on a sound level meter (Bruel and Kjaer, Type 2603) coupled to an octave band analyzer (Bruel and Kjaer, Type 1612). Ambient-noise levels within the critical bands centered at frequencies from 125 to 8000 Hz were all below those essential for pure-tone threshold testing when the average attenuation of the earphone cushions was considered (21).

Experimental Test Equipment

All training and experimental loudness balance procedures were conducted on the equipment which is schematically illustrated in Figure 1. A 1000-Hz tone and a 4000-Hz tone originated from separate oscillators and entered into electronic switches, 1 and 2 (Grason-Stadler, Model 829-D, A in and B in, respectively). An interval timer (Grason-Stadler, Model 471-1), adjoining the electronic switches controlled the on- and off-times of the two signals. A pulse from the interval timer initiated the 1000-Hz reference tone and simultaneously

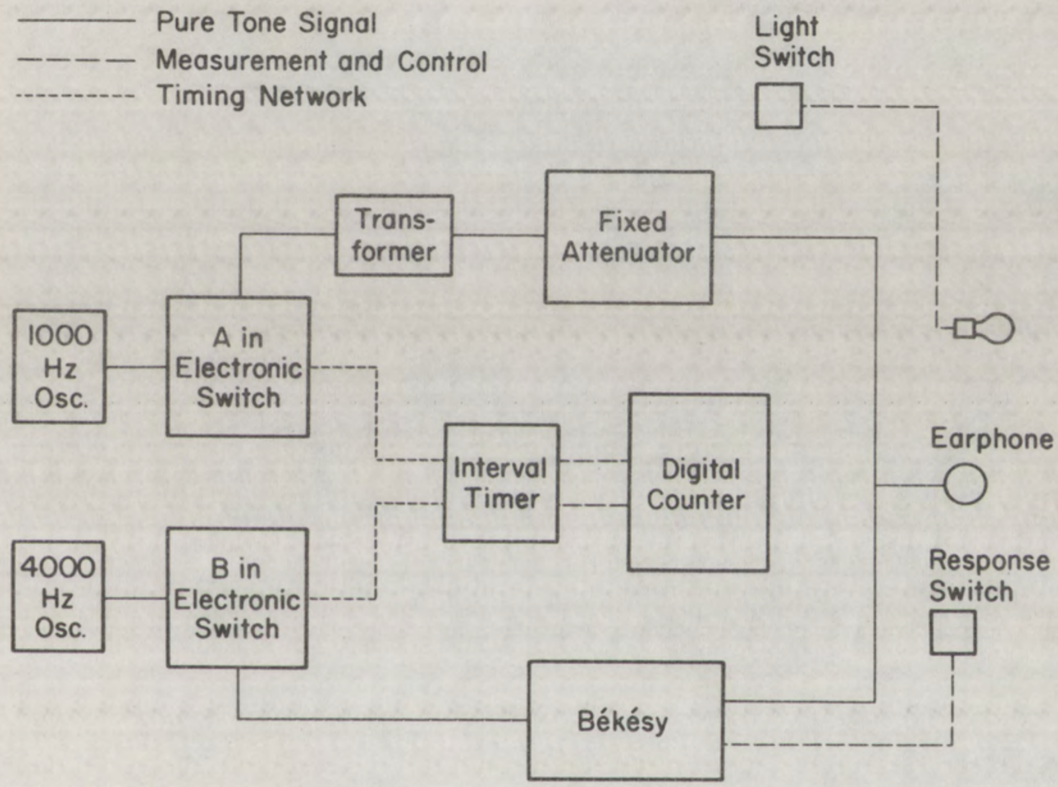

Figure 1. Schematic Illustration of the Experimental Apparatus

terminated the 4000-Hz comparison tone. The two signals overlapped during the 5-msec rise-decay times. From the output of switch A, the 1000-Hz reference signal entered the fixed attenuator (Grason-Stadler, Model 162) and through a transformer into a TDH-39 earphone. The 4000-Hz comparison signal passed from the output of switch B through the recording attenuator of the Bekesy audiometer (Grason-Stadler, Model 800-E) and into the single TDH-39 earphone. The remaining earphone of the headset was not activated during training or experimental sessions.

All temporal conditions were held to specified values within ± 2 msec with the use of a digital counter (Hewlett-Packard, Model 522-B). Reference and comparison signals, including their 5-msec rise-decay times were monitored via an oscilloscope (Tektronix, Type 503). During calibration, the oscilloscope was connected alternately to the outputs of the two electronic switches. The electronic switches were balanced periodically using the oscilloscope in a manner recommended by the manufacturer. Specified sound pressure levels were checked prior to each test session and were maintained within ± 0.1 dB. All reference and comparison signals were free of audible click transients. The 1000-Hz and 4000-Hz signals from the TDH-39 earphone were applied to an artificial ear (Bruel and Kjaer, Model 158) and then passed to the oscilloscope. In this manner, the signals were monitored for any visible click transients. No visible transients could be observed.

Calibration of sound intensity was performed in the following manner prior to each experimental session (not sooner than 30 minutes after the experimental equipment was turned on). The comparison signal (the 4000-Hz tone) was calibrated at a 50-dB SPL intensity level, peaking the VU meter on the face of the Bekesy audiometer at 0 dB. The pen was placed precisely on the desired intensity point of the Bekesy audiogram (Grason-Stadler, Form CF2A). The fixed intensity 1000-Hz tone was sustained at 50-dB SPL to match the 50-dB SPL position of the Bekesy attenuator for calibration. All pre-session calibrations were checked with an artificial ear (Bruel and Kjaer, Model 158) and a standard 6 cc coupler. The attenuation rate of the Bekesy audiometer, measured by the method described by Hattler (4), was 2.4 dB/second.

Collection of Data

Loudness balances were maintained by the subject via a Bekesy recording attenuator on the fixed frequency Bekesy audiograms. The width of the line drawn by the pen on the write out mechanism was equal to 0.2 dB on the Bekesy audiogram.

Loudness balance tracings were quantitatively evaluated at various time intervals during the 4-minute tracking period. The high- and low-intensity peaks of the Bekesy tracings were estimated to the nearest 0.1 dB at the time points of 1/4, 1/2, 1, 1-1/2, 2, 3, and 4 minutes after the commencement of loudness balancing. A technical ruler graduated in 1 dB steps and an illuminated magnifying glass (Bausch and Lomb, No. 813980) were employed in data collection. The accuracy and reliability of this method of measuring Bekesy tracings has been documented by Hattler (4).

The mean midpoint was calculated for each of the seven time-analysis points. The high- and low-intensity peaks immediately preceding and immediately following the analysis points were averaged. Each tracking level represented an average of four high- and low-intensity peaks which surrounded the point. In all, the study consisted of 5, 040 bits of data.

Procedure

Screening and Training

Subjects were given a thirty minute training session in which they were instructed to perform alternate monaural loudness balances. A 1000-Hz reference tone was fixed at 50-dB SPL. The intensity of the comparison signal, a 4000-Hz tone, was varied via the Bekesy audiometer. Right and left ears were counterbalanced among subjects. Subjects were instructed to produce the sensation of equal loudness for the reference (1000-Hz) tone and comparison (4000-Hz) tone.

Instructions for the training sessions were as follows:

> You will hear two tones of different frequency or pitch pulsing alternately in your right (or left) ear. The length of the two tones will vary; at times they will be equal and at other times they will not. Listen to the tone of lower frequency or pitch and attempt to match the loudness of the higher frequency tone to it using this hand switch. When the higher pitched tone becomes louder than the other, press the switch and hold it until the tone is too soft to have equal loudness with the lower pitch. Pay attention to the relative loudness of the two tones and to nothing else you may hear. You will be signaled with the light five seconds before you hear the tones.

Tones of equal duty cycles (50% duty cycle) and differing duty cycles (e.g. 20% vs. 80%) were presented. Subjects were screened for ability to maintain a relatively stable loudness balance tracing for 2 to 3 minutes after commencement of balances for tones with equal duty cycles. The presentation of tones with unequal duty cycles during the training sessions was to allow each subject pre-experimental practice in balancing these particular signals.

Experimental Sessions

Subjects were alternately presented a 1000-Hz reference tone (R), and a 4000-Hz comparison tone (C) to one ear. Temporal parameters of the tones were such that the differences (D) in duty cycle of the two signals were equal to 0, 30, 60, and 80%. Table 1 contains the temporal parameters of the 1000-Hz reference and 4000-Hz comparison signals with the reference signals having a relatively high duty cycle and the comparison signals having a low duty cycle ($R_H C_L$). Temporal parameters with a low duty cycle reference signal and high duty cycle comparison signal ($R_L C_H$) are shown in Table 2. All duty cycle difference (D) conditions are illustrated in Figure 2.

The four duty cycle D conditions were presented in sets of three. The equal duty cycle conditions (D_0) were presented before and after the disparate duty cycle conditions (i.e. 0-30-0, 0-60-0, 0-80-0). As such, each set was presented twice, with the reference tone having both a high and a low duty cycle relative to the comparison signal (i.e. $R_H C_L$ vs. $R_L C_H$). Each subject loudness balanced six sets of duty cycle conditions which were presented in a random order.

Subjects were alerted to the commencement of each 4-minute tracking period by a 5-second warning light. The reference signal was presented at 50-dB SPL and the comparison signal was presented at 57-dB SPL, the intensity at which subjects tended to loudness balance the two tones during the equal duty cycle runs (D_0) of the training

TABLE 1

TEMPORAL PARAMETERS OF ALTERNATE LOUDNESS BALANCE SIGNALS FOR $R_H C_L$ TRIALS

	REFERENCE TONE 1000 Hz					COMPARISON TONE 4000 Hz			
Disparity of Duty Cycle %	On Time msec	Off Time msec	Rep. Rate IPS	Duty Cycle %	Disparity of Duty Cycle %	On Time msec	Off Time msec	Rep. Rate IPS	Duty Cycle %
D_0	200	200	2.5	50	D_0	200	200	2.5	50
D_{30}	375	200	1.75	65	D_{30}	200	375	1.75	35
D_{60}	800	200	1.0	80	D_{60}	200	800	1.0	20
D_{80}	1800	200	0.5	90	D_{80}	200	1800	0.5	10

TABLE 2

TEMPORAL PARAMETERS OF ALTERNATE LOUDNESS BALANCE SIGNALS FOR $R_L C_H$ TRIALS

	REFERENCE TONE 1000 Hz					COMPARISON TONE 4000 Hz			
Disparity of Duty Cycle %	On Time msec	Off Time msec	Rep. Rate IPS	Duty Cycle %	Disparity of Duty Cycle %	On Time msec	Off Time msec	Rep. Rate IPS	Duty Cycle %
D_0	200	200	2.5	50	D_0	200	200	2.5	50
D_{30}	200	375	1.75	35	D_{30}	375	200	1.75	65
D_{60}	200	800	1.0	20	D_{60}	800	200	1.0	80
D_{80}	200	1800	0.5	10	D_{80}	1800	200	0.5	90

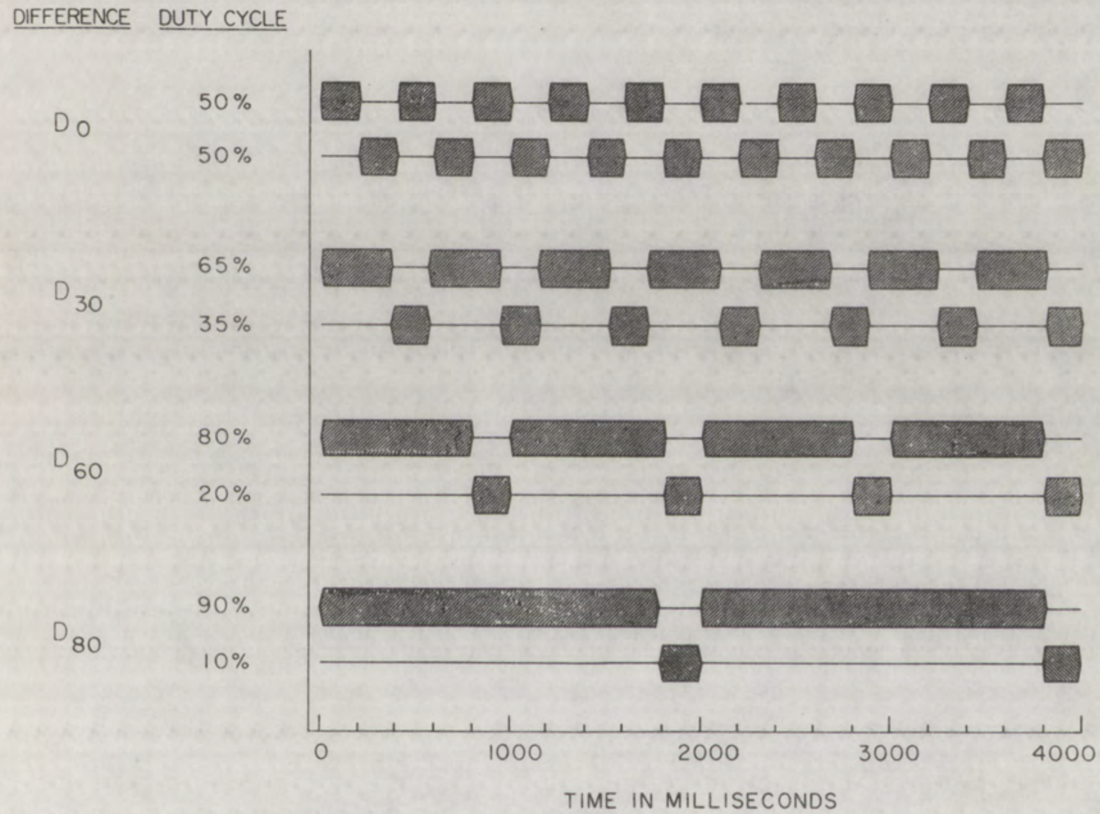

Figure 2. Schematic Representation of the Four Signal Pairs Employed during the Alternate Monaural Loudness Balances

sessions. The comparison increased in intensity until the Bekesy switch was depressed and decreased in intensity until the switch was released. Each 4-minute balancing period was separated by a one-minute rest period during which the earphone headset remained in place. After every third 4-minute balancing period (or set) the earphones were removed and a rest period of 10 minutes was allowed. The experiment was completed in two test sessions with three experimental sets per session. Instructions given prior to each test session were identical to those given before the training sessions.

Summary

The primary purpose of the present investigation was to determine the effect of duty cycle upon monaural loudness balances over an extended period of time. A reference and a comparison signal, presented alternately, differed in duty cycle by 0, 30, 60, and 80%. Conditions of both high- and low-duty cycle reference tones relative to the comparison tone were presented randomly for each of the disparate duty cycle parameters. Subjects were asked to adjust the comparison signal to equal the loudness of the reference signal by use of a Bekesy switch. The experiment constituted a combination of the method of limits and the method of adjustment by employing the alternate monaural loudness balance technique via the Bekesy audiometer in a pursuit auditory loudness tracking task.

CHAPTER IV

RESULTS, ANALYSIS AND DISCUSSION

Introduction

The present investigation was designed to study the effects of duty cycle upon the loudness of pulsed tones. Ten normal hearing subjects were instructed to perform alternate monaural loudness balances employing a 1000-Hz reference tone fixed at 50-dB SPL and a variable intensity 4000-Hz comparison tone. The following effects on loudness balances were studied: equality vs. disparity of duty cycle, duty cycle of the reference signal vs. duty cycle of the comparison signal, and the effects of the passage of time after commencement of tracking.

Results

Comparison Data

Any changes in the loudness relationship between the reference and comparison signals were reflected in the loudness balance tracings which were analyzed at various points along the 4-minute tracking period. If a duty cycle effect did not occur (i.e. if no loudness difference was present between the D_0 and a disparate duty cycle condition) the relative difference between the two conditions would be 0 dB.

The combined duty cycle effects for all the data (R_HC_L and R_LC_H) are represented in Table 3 and Figure 3. In the D_{30} condition, the duty cycle effect (relative dB) increased from t = 1/4 to t = 2 minutes and then decreased. During the D_{60} and D_{80} conditions, the duty cycle effect grew to t = 2 minutes then remained relatively stable. The duty cycle effect (relative dB) averaged 2.7 dB, 3.1 dB and 3.5 dB

TABLE 3

COMBINED DUTY CYCLE EFFECTS (RELATIVE dB) FOR $R_H C_L$ AND $R_L C_H$

TIME AFTER START OF TRACKING (MIN)	DIFFERENCE IN DUTY CYCLE % D_{30}	D_{60}	D_{80}	MEAN
1/4	1.5	0.9	1.4	1.3
1/2	1.9	2.3	3.0	2.4
1	1.5	3.3	3.5	2.8
1-1/2	3.0	2.9	3.8	3.3
2	3.9	4.4	4.2	4.2
3	2.3	4.1	4.1	3.5
4	3.2	3.2	4.0	3.4
MEAN	2.7	3.1	3.5	3.1

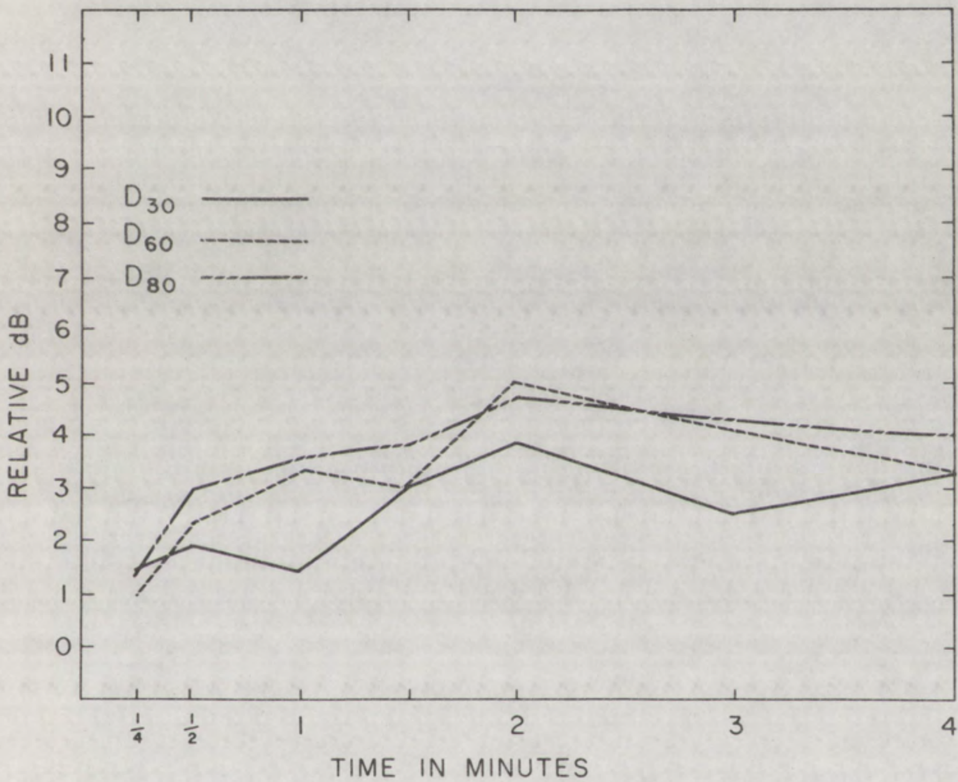

Figure 3. Intensity Differences (relative dB) for Equal Loudness as a Function of Time Averaged Over All Conditions. The parameter is a Difference in Duty Cycle.

for D_{30}, D_{60} and D_{80}, respectively, for all loudness balances over the entire 4-minute tracking period.

Duty cycle effects, as a function of time, for the high reference ($R_H C_L$) loudness balances are given in Table 4 and Figure 4. For the D_{30} condition, the duty cycle effect increased up to t = 2 minutes and then decreased. For D_{60} and D_{80} tracings, there was a consistent growth in the duty cycle effect for the first 3 minutes of tracking. Beyond t = 1 minute, the duty cycle effect was progressively greater as the disparity of duty cycles was increased. For example, at t = 2 minutes, the duty cycle effect was 4.5 dB (for D_{30}), 6.8 (for D_{60}) and 7.4 dB (for D_{80}). At t = 3 minutes, the duty cycle effect equalled 2.7 dB, 6.9 dB and 7.9 dB for the D_{30}, D_{60} and D_{80} conditions, respectively. Averaged over the entire 4-minute tracking period, the duty cycle effect was directly related to the size of the duty cycle disparity (3.0 dB for D_{30}, 5.7 dB for D_{60} and 6.8 dB for D_{80}). When the factors of time and duty cycle D were collapsed, the over-all duty cycle effect averaged 5.1 dB for all $R_H C_L$ balances.

Table 5 and Figure 5 contain the results of $R_L C_H$ balances. For the D_{30}, D_{60} and D_{80} conditions, there was a steady growth in duty cycle effect from t = 1.4 to t = 2 minutes. The data were relatively unchanged beyond t = 2 minutes. Beyond t = 2 there appears to be an inverse relationship between the relative dB data and the size of the duty cycle disparity for $R_L C_H$ balances. In general, very little of the expected duty cycle effect was observed during $R_L C_H$ conditions.

The differences in the duty cycle effects of $R_H C_L$ and $R_L C_H$ balances are presented in Table 6 and Figure 6. For D_{30} balances, $R_H C_L$ and $R_L C_H$ trials yielded similar data. (The mean difference in

TABLE 4

DUTY CYCLE EFFECTS (RELATIVE dB) FOR $R_H C_L$

TIME AFTER START OF TRACKING (MIN)	DIFFERENCE IN DUTY CYCLE % D_{30}	D_{60}	D_{80}	MEAN
1/4	1.9	3.1	4.5	3.2
1/2	2.7	5.5	6.9	5.0
1	2.8	7.8	7.0	5.9
1-1/2	3.0	5.3	6.4	4.9
2	4.5	6.8	7.4	6.2
3	2.7	6.9	7.9	5.8
4	3.1	4.2	7.2	4.8
MEAN	3.0	5.7	6.8	5.1

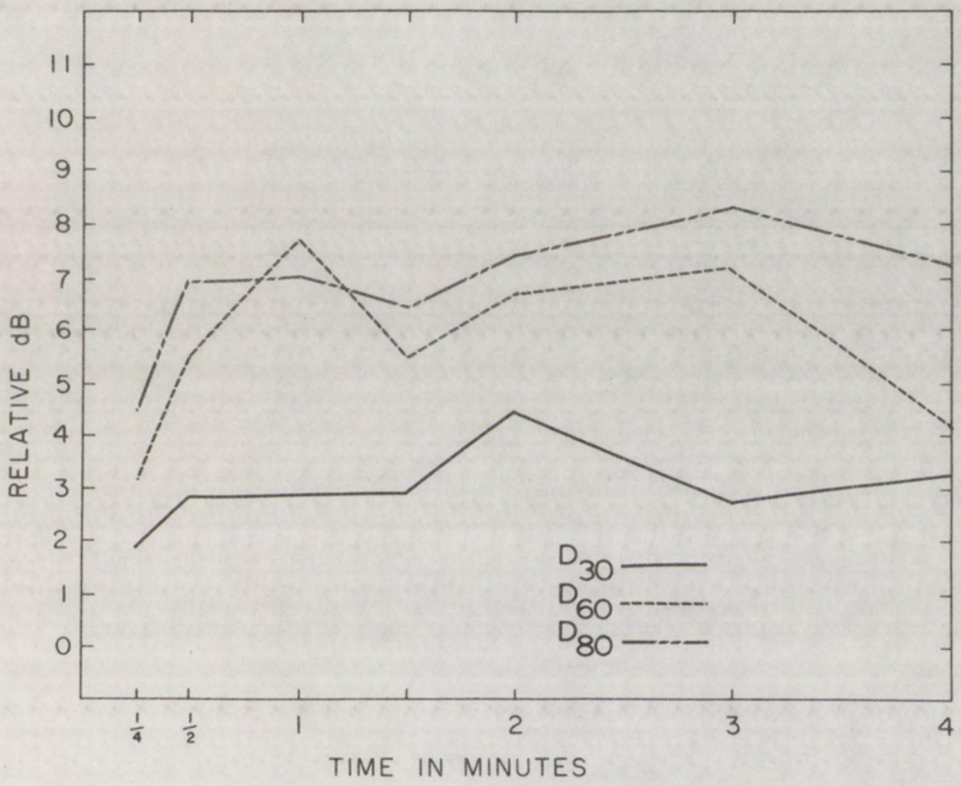

Figure 4. Duty Cycle Effects (relative dB) for $R_H C_L$ Conditions

TABLE 5

DUTY CYCLE EFFECTS (RELATIVE dB) FOR $R_L C_H$

TIME AFTER START OF TRACKING (MIN)	DIFFERENCE IN DUTY CYCLE % D_{30}	D_{60}	D_{80}	MEAN
1/4	1.1	-1.2	-1.5	-0.5
1/2	1.0	-0.8	-0.7	-0.1
1	2.3	-0.1	0.1	0.7
1-1/2	3.1	0.5	1.2	1.6
2	3.3	1.8	1.1	1.8
3	1.9	1.2	0.4	1.1
4	3.3	2.2	0.7	2.0
MEAN	2.4	0.5	0.1	1.0

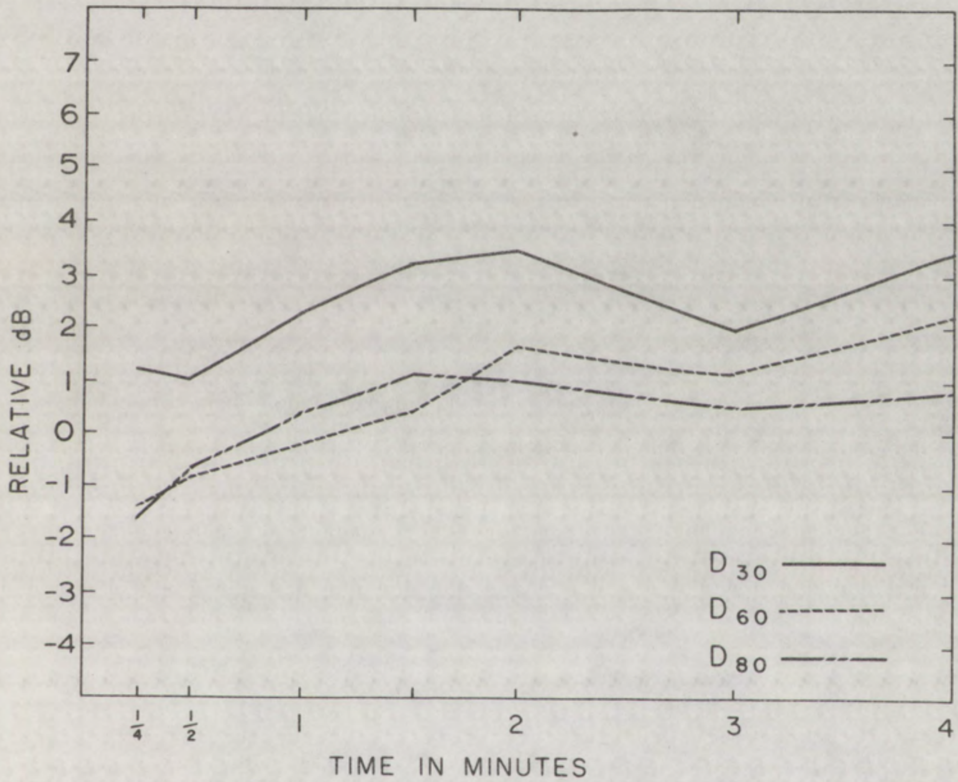

Figure 5. Duty Cycle Effects (relative dB) for $R_L C_H$ Conditions

TABLE 6

DUTY CYCLE EFFECTS (RELATIVE dB) FOR $R_H C_L$ MINUS DUTY CYCLE EFFECTS FOR $R_L C_H$

TIME AFTER START OF TRACKING (MIN)	DIFFERENCE IN DUTY CYCLE % D_{30}	D_{60}	D_{80}	MEAN
1/4	0.7	4.4	6.0	3.7
1/2	1.7	6.3	7.7	5.2
1	0.5	8.0	6.9	5.1
1-1/2	-0.1	4.8	5.2	3.3
2	1.2	4.9	6.2	4.1
3	0.8	5.7	7.5	4.6
4	-0.1	1.9	6.5	2.6
MEAN	0.8	5.1	6.6	4.1

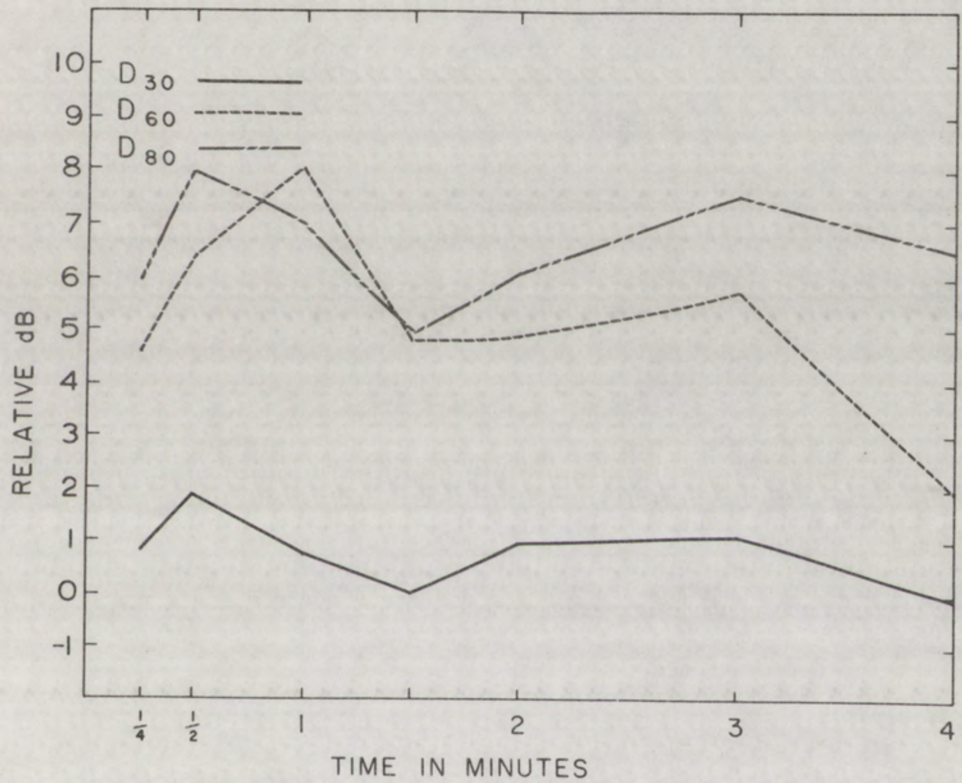

Figure 6. Duty Cycle Effects (relative dB) for $R_H C_L$ Balances Minus Duty Cycle Effects for $R_L C_H$

relative dB was only 0.8 dB.) For the D_{60} and D_{80} conditions, however, R_HC_L balances yielded greater duty cycle effects than did R_LC_H balances. Beyond t = 1-1/2 minutes, the differences increased as the disparity of duty cycles was increased.

Reference Data

D_0 loudness balances were presented before and after each disparate duty cycle condition. D_0 data are represented in Table 9 and Figure 8 (Appendix). A growth in intensity of the comparison tone (in order to maintain equal loudness balances) is apparent for D_0 balances in both R_HC_L and R_LC_H trials. During R_HC_L balances, the intensity of the 4000-Hz comparison tone grew from 60.6-dB SPL at t = 1/4 minute to 64.1-dB SPL at t = 4 minutes. D_0 balances before and after the R_HC_L conditions were consistently lower in intensity than those adjacent to the R_LC_H balances throughout the 4-minute tracking period.

Summary

Definite duty cycle effects were noted when all the data were combined. Duty cycle effects were greater for the R_HC_L conditions than for R_LC_H conditions. For R_HC_L, the duty cycle effect increased as duty cycle differences were increased; while in R_LC_H balances, a decrease in duty cycle effect was observed as the duty cycle differences were increased. D_0 (equal duty cycle) balances resulted in a drifting of the 4000-Hz comparison tone intensity to higher SPL's during the 4-minute tracking period for both R_HC_L and R_LC_H conditions, with the latter condition having a more pronounced effect.

Analysis of the Results

A split plot design (11, 23) was employed in the analysis of the data. A summary of the analysis of variance for the entire experiment is found in Table 7. There was a linear growth in the duty cycle effect (relative dB) with the passage of time after commencement of tracking ($p < 0.05$). D_{30} balances for $R_H C_L$ conditions were not significantly different from D_{30} balances for the $R_L C_H$ conditions. Both D_{30} conditions yielded a clear duty cycle effect. D_{60} and D_{80} balances yielded duty cycle effects within $R_H C_L$ balances; however, the duty cycle effect was curiously absent with $R_L C_H$ conditions (see Figure 7). Therefore, the $R_H C_L$ vs. $R_L C_H$ factor yielded significant differences at the 0.01 level of confidence. Consequently, monaural loudness balance behavior for D_{30} differed significantly from behavior for D_{60} and D_{80} in the respective $R_H C_L$ and $R_L C_H$ conditions.

Discussion of the Present Results and Comparison with Previous Investigations

The results of the present investigation support the hypothesis that the relative loudness of two signals is dependent, in part, upon their duty cycles. The duty cycle effect is related to the factor of time after commencement of loudness balancing. Another determining factor is whether the high duty cycle signal is the referencc or the comparison. Whenever the high duty-cycle signals were fixed in intensity (as the reference signal), the duty cycle effects were orderly and in the expected direction. The higher the duty cycle, in these conditions, the louder was the signal despite the use of fixed (reference) intensities and frequencies. Similarly, the lower the duty cycle, the less was the perceived loudness. During loudness balances, subjects

TABLE 7

ANALYSIS OF VARIANCE

SOURCE	df		MEAN SQUARE	F
SUBJECT (S)	9		459.598	
DUTY CYCLE	2		20.438	1
D_{60} vs. D_{80}		1	13.827	1
D_{30} vs. (D_{60} & D_{80})		1		
EXPERIMENT (E) ($R_H C_L$ vs. $R_L C_H$)	1		1462.945	12.0**
D x E	2		327.422	2.74
(D_{60} vs. D_{80})		1	138.292	1.0
(D_{30} vs. (D_{60} & D_{80})) x E		1	516.544	4.314*
ERROR (SxD, SxE, SxDxE)	45		119.754	
TIME (T)	6		27.619	1.778
Time Linear		1	136.310	8.773*
T x D	12		4.065	1
T x E	6		10.205	1
T x D x E	12		7.500	1
ERROR	324		15.537	

*Significant at 5%

**Significant at 1%

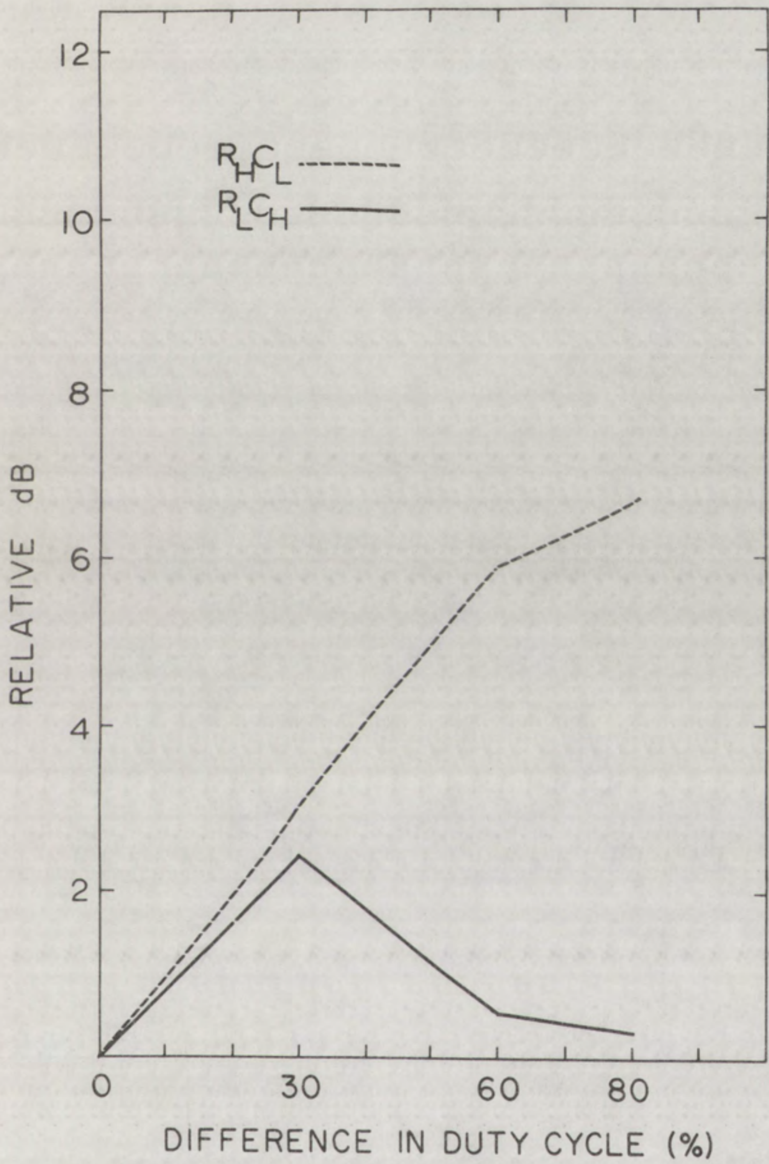

Figure 7. Intensity Differences (relative dB) as a Function of Duty Cycle Difference for R_HC_L and R_LC_H Conditions

adjusted the intensity of the comparison tone in compensation for these duty cycle effects upon loudness.

A separate set of circumstances appear to influence loudness balances when the lower duty cycle is fixed (and employed as the reference loudness) and the higher duty cycle (the comparison loudness) is adjusted via the Bekesy audiometer. The duty cycle effects are apparently overshadowed by some other mechanism which is not clearly defined at this time. A possible explanation for this phenomenon is that the auditory system arrives at some "average loudness" whenever the intensity of a high duty cycle signal is being varied during its on-duration. The changing intensity of the tone may result in a reduction of the perceived loudness of a high duty-cycle tone as compared to the situation in which the intensity is fixed. In the case where the low duty cycle was varying via the Bekesy audiometer, most of the intensity variation occurred during the off-time. On-durations were too short (200 msec) to allow for "loudness averaging" of high- and low-intensity peaks as the Bekesy attenuator changed directions. During $R_L C_H$ balances, the on-durations were 800 msec and 1800 msec, respectively. Intensity variations were clearly noticeable during $R_L C_H$ balances in which these relatively long tones varied via the Bekesy. Further research is needed in which duty cycle effects on loudness can be investigated without the use of a Bekesy attenuator. This should eliminate any "loudness averaging" effects which may have occurred in the present sutyd.

Another possibility is that the 4000-Hz comparison tone yielded some degree of loudness adaptation when the signal had a high duty cycle ($R_L C_H$) and none when the comparison had a low duty cycle

($R_H C_L$). In this situation, as in the first hypothesis, subjects would find it necessary to produce a relatively higher SPL than would otherwise be required to affect equal loudness balances. A higher comparison tone SPL would tend to eradicate any existing duty cycle effects. Thus, duty cycle effects and either "loudness averaging" or loudness "adaptation" might cancel each other out and relative dB difference would approach the zero point as in D_{60} and D_{80} balances (Figure 7).

The present results are nearly identical to those of Hattler and Stokinger (8) who used an ABLB technique with and without a silent interval between reference and comparison signals. A comparison of data in all duty cycle conditions from the present investigation and that of Hattler and Stokinger is found in Table 8. Less duty cycle effects are shown for monaural loudness balances in all but one of the disparate duty cycle conditions. D_{60} balances within $R_H C_L$ yielded a mean intensity difference of 5.7 dB for monaural loudness balances versus 3.1 dB using the binaural technique. The overall larger duty cycle effect for binaural balances occurred for $R_L C_H$ conditions. ABLB results may be influenced by binaural interaction which possibly could increase the duty cycle-loudness relationship.

The present data can also be compared to loudness tracking data (4) where a tone with a 20% duty cycle and a 200 msec on-time was tracked for three minutes after a 50-dB SPL reference signal was presented. Hattler observed a 13.8-dB growth in the intensity of the pulsed-tone tracing in relation to a continuous-tone tracing. The difference in duty cycles was 80%. The present investigation contained similar duty cycle parameters. The $R_H C_L$ balances for D_{60} yielded a

TABLE 8

DUTY CYCLE EFFECTS (RELATIVE dB) IN THE PRESENT INVESTIGATION COMPARED TO THOSE OF HATTLER AND STOKINGER (1971), (in parentheses)

TIME AFTER START OF TRACKING (MIN)	DIFFERENCE IN DUTY CYCLE % D_{30}	D_{60}	D_{80}	MEAN
		R_HC_L		
1/4	1.9 (-0.9)	3.1 (2.0)	4.5 (5.1)	3.2 (2.1)
1/2	2.7 (0.1)	5.5 (1.8)	6.9 (7.3)	5.0 (3.0)
1	2.8 (0.7)	7.8 (5.1)	7.0 (8.7)	5.9 (4.8)
2	4.5 (3.7)	6.8 (2.2)	7.4 (9.7)	6.2 (5.2)
3	2.7 (4.2)	6.9 (4.0)	7.9 (8.2)	5.8 (5.5)
4	3.1 (5.5)	4.2 (4.9)	7.2 (11.1)	4.8 (7.2)
MEAN	3.0 (2.2)	5.7 (3.1)	6.8 (8.3)	5.1 (4.5)
		R_LC_H		
1/4	1.1 (2.7)	-1.2 (2.0)	-1.5 (1.7)	-0.5 (2.1)
1/2	1.0 (2.7)	-0.8 (2.6)	-0.7 (2.7)	-0.1 (2.7)
1	2.3 (3.9)	-0.1 (3.7)	0.1 (0.5)	0.7 (2.7)
2	3.3 (4.5)	1.8 (4.5)	1.1 (1.4)	1.8 (3.5)
3	1.9 (3.7)	1.2 (3.9)	0.4 (2.5)	1.1 (3.4)
4	3.3 (6.3)	2.2 (2.0)	0.7 (2.3)	2.0 (3.5)
MEAN	2.4 (4.0)	0.5 (3.1)	0.1 (1.9)	1.1 (3.0)
GRAND MEAN	2.7 (3.1)	3.1 (3.1)	3.5 (5.1)	3.1 (3.8)

duty cycle effect of 5.7 dB and D_{80} yielded a duty cycle effect of 6.8 dB. In loudness tracking experiments, the reference tone is presented briefly prior to commencement of tracking. The subject is forced to remember or recall the reference loudness and to maintain it during tracking. The recalled loudness may drift (increase) over time thus forcing the subject to yield a higher SPL during tracking with a low duty cycle tone in order to match the recalled reference loudness. Periodic presentation of the reference tone, as in the AMLB technique employed in the present investigation, eliminates the need for long-term loudness memory. The duty cycle effects on loudness appear to be reduced when the reference tone is alternated with the comparison tone in both AMLB and ABLB techniques.

During D_0 balances, or loudness balances with tones of equal duty cycles, the intensity of the comparison signal drifted curiously with the passage of time. At the initiation of tracking (Figure 8), the intensity levels of the 4000-Hz (comparison) signal approximated the equal loudness data of Fletcher and Munson (3) when a 4000-Ha tone is compared to a 1000-Hz tone. However, a continual growth in the intensity level of the comparison signal tended to eradicate the duty cycle effect upon loudness since the D_0 loudness balances were used as the reference data in the experiment. A greater increase in the intensity of the comparison signal was noted during $R_L C_H$ balances which could explain the apparent lack of duty cycle effect during this condition. When the ABLB technique was employed (5) during D_0 balances, the intensity of the comparison data remained relatively stable over time.

CHAPTER V

SUMMARY

Introduction

The relationship between the duty cycle of repeated signals and perceived loudness has been studied using binaural loudness balances and loudness tracking techniques (5, 8). These experiments have yielded some insight into the LOT phenomenon (5) and the Type V Bekesy pattern (9). However, it was found necessary to use a monaural loudness balance technique in the study of duty cycle effects upon loudness in order to avoid any binaural interaction effects which could have existed in past experimentation.

The factors under investigation in the present study included: the difference (D) in duty cycle between a reference and a comparison signal; the use of a relatively high vs. a relatively low duty cycle reference signal ($R_H C_L$ vs. $R_L C_H$) during disparate duty cycle conditions; and the effect of time after commencement of loudness balances. The data added further understanding of the LOT and Type V phenomena and information was gained regarding relationships between alternate binaural and alternate monaural loudness balancing techniques.

Procedure and Experimental Design

Ten normal hearing subjects performed alternate monaural loudness balances over four-minute trials. Equal loudness was maintained between a fixed-intensity reference signal of 1000-Hz and a variable-intensity 4000-Hz comparison signal. The experimenter adjusted the duty cycles of the signals from trial to trial so that duty cycle differences between the two tones ranged from 0 to 80 percent.

The reference signals had both relatively high and relatively low duty cycle during the trials in which there was a difference in duty cycle between the two loudness-balanced tones ($R_H C_L$ vs. $R_L C_H$). The loudness balances in which the two signals had equal duty cycles (D_0) were presented before and after the D_{30}, D_{60}, and D_{80} loudness balances and were used as control conditions to which disparate duty cycle data were compared. Intensity differences in dB SPL between the D_0 and the D_{30}, D_{60} and D_{80} trials were used to measure the duty cycle effect upon loudness and were analyzed at the t = 1/4, 1/2, 1, 1-1/2, 2, 3, and 4 minute time points.

Results

The results show that the loudness of repeated pulsed signals is dependent, in part, upon the duty cycle of the signals.

Analysis of the entire experiment (including both $R_H C_L$ and $R_L C_H$ balances) revealed the following:

1. Duty cycle effects for $R_H C_L$ balances were significantly different from the effects for $R_L C_H$ balances ($p < 0.01$).

2. A significant growth in duty cycle effect was noted over the passage of time for both $R_H C_L$ and $R_L C_H$ balances ($p < 0.05$).

3. D_{30} loudness balances differed significantly from D_{60} and D_{80} balances in their respective $R_H C_L$ and $R_L C_H$ conditions.

Additional Comparisons

$R_H C_L$ balances yielded a definite duty cycle effect which grew in relative intensity as the duty cycle differences between the two signals was increased. Duty cycle effects (relative dB) for $R_L C_H$ balances were completely opposite in that they decreased as the disparity of duty cycle between the signals was increased.

Conclusions and Suggestions for Further Research

A definite effect of duty cycle upon loudness, increasing with the passage of time, was noted in this experiment. This duty cycle effect was slightly less than that noted using the ABLB technique, and was considerably less than duty cycle effects upon loudness during loudness tracking. In one part of the study there was an orderly increase in loudness perception as the duty cycle was increased. This effect was totally opposite in a second part of the experiment due to some unknown variable. Because of this puzzling variable it is suggested that further research concerned with duty cycle effects upon loudness (over extended time periods) be performed without the automatic attenuation of a Bekesy audiometer in order to omit any possible loudness averaging phenomena.

APPENDIX

TABLE 9

MEAN TRACKING LEVEL (dB SPL) FOR THE AVERAGE OF TWO LOUDNESS BALANCES IN WHICH BOTH REFERENCE AND COMPARISON SIGNALS HAVE THE SAME DUTY CYCLE (D_0)

TIME AFTER START OF TRACKING (MIN)	CONDITION IN WHICH DATA OCCURRED D_{30}	D_{60}	D_{80}	MEAN
		$R_H C_L$		
1/4	59.4	61.3	61.0	60.6
1/2	60.5	61.5	62.3	61.4
1	62.0	63.4	62.3	62.6
1-1/2	62.0	64.5	63.4	63.3
2	62.0	63.7	63.1	62.9
3	62.5	65.2	63.6	63.6
4	62.9	65.6	64.7	64.1
MEAN	61.6	63.6	62.9	62.7
		$R_L C_H$		
1/4	61.8	60.5	60.5	60.9
1/2	62.1	61.8	61.6	61.8
1	62.8	62.8	63.7	63.1
1-1/2	63.4	63.8	65.6	64.2
2	63.6	64.9	65.4	64.4
3	61.9	65.5	66.2	61.2
4	63.6	65.6	66.7	65.3
MEAN	62.7	63.6	64.2	63.5
GRAND MEAN	62.2	63.6	63.6	63.1

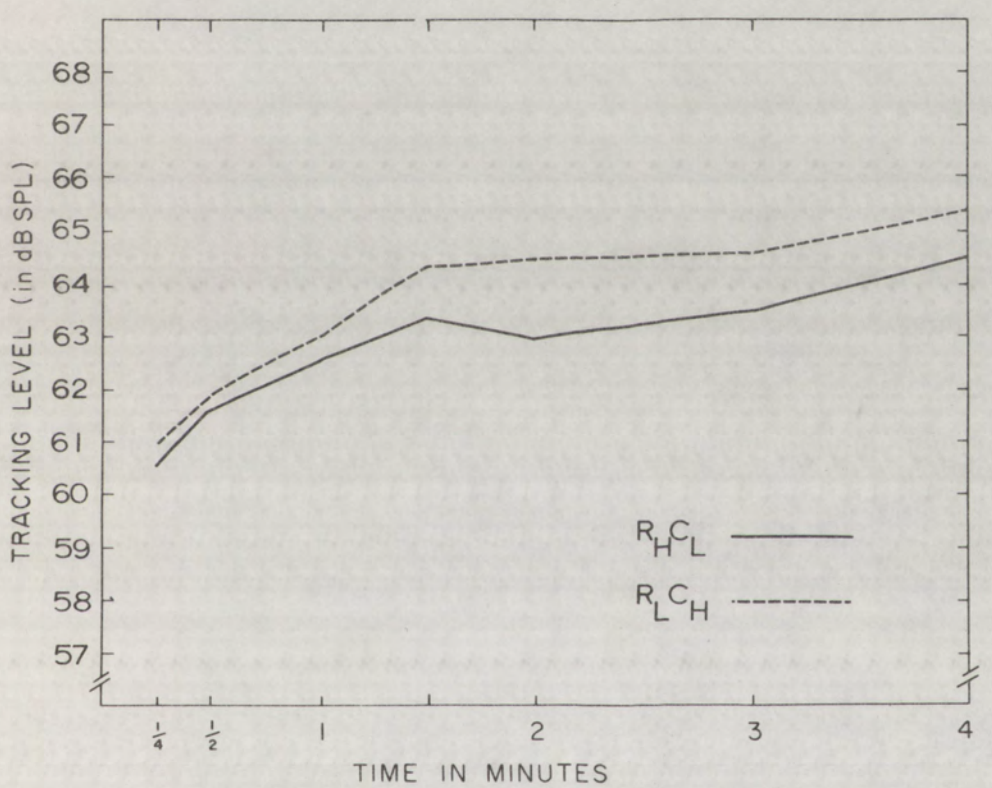

Figure 8. Mean Tracking Level (dB SPL) of the Comparison Tone for D_0 Balances Within R_HC_L and R_LC_H Conditions

BIBLIOGRAPHY

1. Bekesy, G. von. Experiments in Hearing. New York: Mc-Graw-Hill Book Co., Inc., 1960.

2. Ehmer, R.H. and Ehmer, B.J. Frequency pattern of residual masking by pure tones measured on the Bekesy audiometer. J. Acoust. Soc. Am., 46, 1445-1448, 1969.

3. Fletcher, H. and Munson, W.A. Loudness, its definition, measurement and calculation. J. Acoust. Soc. Am., 5, 82-108, 1933.

4. Hattler, K.W. "Loudness tracking: the effects of loudness memory." M.S. Thesis, Univ. of Oklahoma, 1967.

5. Hattler, K.W. The Type V Bekesy Pattern: The effects of loudness memory. J. Speech Hear. Res., 11, 567-575, 1968.

6. Hattler, K.W. "Alternate binaural loudness balance with tones of unequal duty cycle." Ph.D. Dissertation, Univ. of Oklahoma, 1971.

7. Hattler, K.W. and Dixon, S. Effects of sensation level on loudness tracking. Paper presented at the 85th meeting of the Acoustical Society of America, Boston, April, 1973.

8. Hattler, K.W. and Stokinger, T.E. Loudness balances employing signals with unequal duty cycles. J. Acoust. Soc. Am., 52, 558-565, 1972.

9. Jerger, J. and Herer, G. An unexpected dividend in Bekesy audiometry. J. Speech Hear. Dis., 26, 390-391, 1961.

10. Kingsbury, B.A. A direct comparison of the loudness of pure tones. Phys. Rev., 29, 588-600, 1927.

11. Mendenhall, W. Introduction to Linear Models and the Design and Analysis of Experiments. Belmont, Calif.: Wadsworth Publishing Co., Inc., 1968.

12. Mirabella, A., Taub, H., and Teichner, W.H. Adaptation of loudness of monaural stimulation. Jour. Gen. Psych., 76, 251-273, 1967.

13. Miskolczy-Fodor, F. Relation between loudness and duration of tonal pulses: I. Response of normal ears to pure tones longer than click-pitch threshold. J. Acoust. Soc. Am., 31, 1128-1132, 1959.

14. Pikler, A.G. and Harris, J.D. Compensatory and pursuit tracking of loudness. J. Acoust. Soc. Am., 32, 1129-1133, 1960.

15. Raab, D.H. Backward masking. Psych. Bull., 60, 118-129, 1963.

16. Reger, S.N. Difference in loudness response of the normal and hard-of-hearing ear at intensity levels slightly above threshold. Ann. Otol. Rhinol. Laryng., 45, 1029-1036, 1936.

17. Resnick, D.M. and Burke, K.S. Bekesy audiometry in non-organic auditory problems. Arch. Otol., 76, 38-41, 1962.

18. Rintelmann, W.F. and Carhart, R. Loudness tracking by normal hearers via Bekesy audiometer. J. Speech Hear. Res., 7, 79-93, 1964.

19. Samoilova, I.K. (Masking of brief tonal signals which precede the masking sounds.) Probl. Fiziol. Akust., 4, 38-44, 1959.

20. Samoilova, I.K. Masking of short tone signals as a function of the time interval between masked and masking sounds. Biophysics, 4, 44-52, 1959.

21. Shaw, W.A.. Measurements of Insulation and Sensitivity of Service Headsets. Cambridge, Mass.: Psycho-Acoustic Laboratory, OSRD Report No. 6113, 1945. Cited by I. Hirsh, The Measurement of Hearing. New York: McGraw-Hill Book Co., Inc., 1952.

22. Small, A.M., Brandt, J.F. and Cox, P.G. Loudness as a function of signal duration. J. Acoust. Soc. Am., 34, 513-514, 1962.

23. Snedecor, A.W. and Cochran, W.G. Statistical Methods. Iowa City: Iowa State Univ. Press, 1967.

24. Stokinger, T.E., Cooper, W.A. Jr. and Meissner, W.A. Influence of binaural interaction on the measurement of perstimulatory loudness adaptation. J. Acoust. Soc. Am., 51, 602-607, 1972.

25. Stokinger, T.E., Cooper, W.A., Jr., Meissner, W.A. and Jones, K.O. Intensity, frequency and duration effects in the measurement of monaural perstimulatory loudness adaptation. J. Acoust. Soc. Am., 51, 608-616, 1972.