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Group Wisdom and Omnaural Perception: Discovering Frequency Differences by Averaging the Retrospective Time Estimates of Listeners

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Abstract

An audio stimulation experiment analyzed the ways in which frequency combinations and auditory beats affect the perception of time. Evidence of group wisdom regarding difference frequencies was derived by averaging the retrospective time estimates of groups who listened to three minutes of various sine wave combinations. A difference of 14 cycles per second in carrier frequencies corresponded to differences of 14 seconds between the average time estimates of groups who heard the two carrier frequencies. Groups thereby "perceived" the difference between two carrier frequencies when no individual heard more than one carrier frequency and no individual communicated with any other individual. This new phenomenon of group wisdom, here identified as omnaural perception, corresponded to basic patterns in EEG data from each group. Omnaural perception was evident in sets of groups even when individuals heard different rates of auditory beats. Omnaural perception also occurred for groups regardless of whether auditory beats were produced monaurally or binaurally for each individual. Indirect applications of this research involve the development of frequency combinations which can lead to an increase the perceived speed of time.

***Keywords**: group wisdom, time perception, monaural beats, binaural beats, omnaural perception*

1. Introduction

Cases of group wisdom have been documented and studied for over a century. Sir Francis Galton noticed the phenomenon in 1907 at a livestock fair during which approximately 800 villagers participated in a contest to guess the weight of an ox [1]. The ox weighed 1,198 pounds, and Galton found that the mean of all the villagers' guesses was 1,197 pounds [2].

Other examples of group wisdom involve guessing the amount of jelly beans in a jar [3], estimating temperature [4], and even predicting the outcome of sports events [5]. In a variety of situations, group wisdom often entails that the average guess of a group can reach remarkable levels of accuracy which go far beyond the capacities of most individuals.

This experiment explores group wisdom as it applies to the measurement of time and frequency. For a period of three minutes, subjects listened to a constant carrier frequency created by series of changing sine wave combinations, and afterward they were asked to estimate how much time had passed. Average time estimates of various groups were tested for accuracy.

None of the groups came close to measuring time accurately via average group estimates. Instead, it appears that the frequency combinations in this experiment caused alterations in the perception of time such that differences between average time estimates of groups who heard

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two different carrier frequencies corresponded to the difference, in cycles per second, between those two carrier frequencies.

Difference frequencies were identified as early as 1714 by the baroque violinist and composer Giuseppe Tartini [6]. He examined new tones and beats caused by certain two-note combinations on his violin, and he explained how the beats could be used to judge intonation and to build musical scales with precision [7]. Musicians have long used auditory beats to tune a variety of instruments [8]. Anecdotal evidence suggests that the inventor of the tuning fork, John Shore, would entertain eighteenth century audiences by striking his invention in unison with a lute string [9]. As the pitch of the string was tuned closer to the pitch of the tuning fork, the difference between the two frequencies would grow smaller and the beat would slow. The beat would disappear when there was no longer a difference between the two frequencies

Audible beats occur when two near-frequency tones are combined. A listener hears neither of the two tones when they are close enough together in pitch. Instead, a listener hears the tone directly between the two tones, an average/carrier frequency, beating at a rate equal to the difference between the two tones, a difference frequency. Beats occur due to constructive and destructive interference between the two sound waves, which can be proved through trigonometric identity [10]. Periodic pulses in volume are created when the maxima and minima of the two waves line up with each other, and this is perceived as a beat when the period is small enough.

A difference frequency can be created and perceived monaurally and binaurally. Monaural beats are audible difference frequencies created by wave interference when two sound waves are mixed as described above. Binaural beats, on the other hand, can be created when the sound waves remain separate. One ear hears one frequency, and the other ear hears the other frequency. Unlike monaural instances, the sound waves do not mix before entering the brain. Binaural beats are thought to be formed when the neural signals produced by each frequency are mixed within the brain [11].

The present research introduces a new category of difference frequency creation and perception. The *omnaural* difference frequencies discovered in this experiment only occur on a group level, and they appear to involve a special case of group wisdom.

In binaural instances the brain can perceive a difference frequency when neither ear has heard both frequencies necessary to create it. In omnaural instances a group can “perceive” a difference frequency when no individual has heard both frequencies necessary to create it.

2. Method

2.1. Participants and Procedure

Results from 64 subjects have been analyzed. All subjects were Chinese students at Zhengzhou University (27 females and 37 males, ages 17-23).

Each subject listened to one of eight audio tracks through headphones and then estimated the amount of time that had passed. Subjects were not aware beforehand that they would be asked to estimate the amount of time that passed while listening to the track. Each track lasted for three minutes.

EEG data was gathered from all subjects while they listened. The EEG made use of dry electrodes, and the headphones did not interfere with the placement of the electrodes.

2.2. Electroencephalograph

The Mindwave is a commercial Brain-Computer Interface providing EEG data from the left frontal cortex. It was released by Neurosky in 2011. The headset has a 3 Hz – 100 Hz hardware filter range with a 1mV pk-pk EEG maximum signal input range. It is wireless, providing real-time data at a sampling rate of 512 Hz. The headset extracts data from a primary electrode at position Fp1 and a reference electrode at position A1, in accordance with the International 20-10 system of EEG electrode placement.

The primary electrode is positioned on the subject's forehead, above the left eyebrow. The reference electrode is clipped to the subject's left earlobe and acts as an electrical circuit grounding to ensure that the subject's body has the same voltage as the headset. The reference electrode also delivers information used in common mode rejection to eliminate ambient noise. Filter protocols reduce noise from muscle activity, electrical devices, and other known frequencies. Additionally, the headset uses a notch filter to eliminate noise from the electrical grid (50 Hz in this case).

Due to the sampling rate of 512 Hz, the ThinkGear ASIC chip runs a 512 point Fast Fourier Transform to output power values for eight frequency bands every second. Neurosky's Communication Protocol for programmers and developers defines these eight frequency bands as follows: delta (0.5 - 2.75 Hz), theta (3.5 - 6.75 Hz), low-alpha (7.5 - 9.25 Hz), high-alpha (10 - 11.75 Hz), low-beta (13 - 16.75 Hz), high-beta (18 - 29.75 Hz), low-gamma (31 - 39.75 Hz), and mid-gamma (41 - 49.75 Hz). An FFT can also be performed manually on the raw signal to acquire data for different frequency band specifications.

2.3. Beat Frequency Design

The beat frequencies in this experiment were created by mixing sine waves using *Structure* software within *Pro Tools LE 8*, with an *Mbox2 Pro* interface. Frequency calculations were verified by recording the sound wave combinations using an Audio Technica AT4033/CL large-diaphragm cardioid condenser microphone and graphing the results as a function of time.

Series of frequency combinations for this experiment were designed to maintain a constant carrier frequency while altering the rate of beats. A listener seems to hear a single, constant tone beating at various speeds. In actuality the earphones are producing a variety of two-frequency combinations. Table 1 outlines this process for a carrier frequency of 40 Hz.

Table 1. Keeping a Constant Carrier Frequency While Altering the Rate of Beats

Frequencies played through earphones	Frequency heard by listener (average/carrier frequency)	Rate of beats (difference frequency)
39 Hz and 41 Hz	40 Hz	2 Hz
38 Hz and 42 Hz	40 Hz	4 Hz
37 Hz and 43 Hz	40 Hz	6 Hz
36 Hz and 44 Hz	40 Hz	8 Hz
35 Hz and 45 Hz	40 Hz	10 Hz
34 Hz and 46 Hz	40 Hz	12 Hz

Combining two near frequencies creates two new frequencies due to constructive and destructive wave interference.

The results can be heard either binaurally or monaurally. In a monaural instance of the first example in Table 1, each ear hears 39 Hz mixed with 41 Hz. The waves interfere in the earphone speakers, and the listener perceives a carrier frequency of 40 Hz beating at a rate of

2 Hz. In a binaural instance of the first example in Table 1, one ear hears 39 Hz while the other ear hears 41 Hz. The two signals interfere in the brain, and the listener perceives a carrier frequency of 40 Hz beating at a rate of 2 Hz.

2.4. Audio Tracks, Properties and Groupings

For this experiment eight audio tracks were created such that half of the tracks maintained a constant carrier frequency of 40 Hz while the other half maintained a constant carrier frequency of 26 Hz. For each set of tracks, half produced a succession of beats that increased in speed (i.e. the distance between the two mixed frequencies increased as time progressed), while the other half produced the opposite succession. For each of these sets, half produced beats monaurally while the other half produced beats binaurally.

Each subject heard only one track. Eight subjects heard each track per grouping. The following eight tracks were used.

Track 1: 40 Hz carrier frequency, monaural beats increasing speed
Track 2: 40 Hz carrier frequency, binaural beats increasing speed
Track 3: 40 Hz carrier frequency, monaural beats decreasing speed
Track 4: 40 Hz carrier frequency, binaural beats decreasing speed
Track 5: 26 Hz carrier frequency, monaural beats increasing speed
Track 6: 26 Hz carrier frequency, binaural beats increasing speed
Track 7: 26 Hz carrier frequency, monaural beats decreasing speed
Track 8: 26 Hz carrier frequency, binaural beats decreasing speed

Groups of subjects can be compared to each other based on common properties of the tracks they heard. In the analysis of this experiment, groupings of sixty-four people have been used. Grouping I, Grouping II, and Grouping III each contain four unique groups to highlight various common properties of the tracks and to analyze their effects.

Grouping I
40 Hz Carrier Frequency, Monaural Beats (tracks 1 and 3)
40 Hz Carrier Frequency, Binaural Beats (tracks 2 and 4)
26 Hz Carrier Frequency, Monaural Beats (tracks 5 and 7)
26 Hz Carrier Frequency, Binaural Beats (tracks 6 and 8)

Grouping II
40 Hz Carrier Frequency, Increasing Beat Speed (tracks 1 and 2)
40 Hz Carrier Frequency, Decreasing Beat Speed (tracks 3 and 4)
26 Hz Carrier Frequency, Increasing Beat Speed (tracks 5 and 6)
26 Hz Carrier Frequency, Decreasing Beat Speed (tracks 7 and 8)

Grouping III
Monaural Beats, Increasing Beat Speed (tracks 1 and 5)
Monaural Beats, Decreasing Beat Speed (tracks 3 and 7)
Binaural Beats, Increasing Beat Speed (tracks 2 and 6)
Binaural Beats, Decreasing Beat Speed (tracks 4 and 8)

3. Results and Discussion

3.1. Average Time Estimate Data

Table 2 displays data about Grouping I, Grouping II, and Grouping III. After averaging each group's time estimates, the groups were arranged sequentially and designated with a letter (*i.e.*, Group A signifies the group with the lowest average time estimate, and Group D signifies the group with the highest average time estimate).

It can be seen that groups A, B, C, and D consist of different subjects in each different grouping. For example, in Grouping I, Group A consists of the subjects who heard binaural beats through a 40 Hz carrier frequency (tracks 2 and 4); in Grouping II, Group A consists of the subjects who heard increasing beat speeds through a 26 Hz carrier frequency (tracks 6 and 8).

Table 2. Average Time Estimates of Groups Arranged Sequentially for Three Groupings

GROUPING I:			
Group Designation	**Average Time Estimate of Group**	**Properties Heard by Group**	**Tracks Heard by Group**
A	2:19	40 Hz Carrier Frequency, Binaural Beats	2, 4
B	2:20	26 Hz Carrier Frequency, Binaural Beats	6, 8
C	2:28	26 Hz Carrier Frequency, Monaural Beats	5, 7
D	2:41	40 Hz Carrier Frequency, Monaural Beats	1, 3
GROUPING II:			
Group Designation	**Average Time Estimate of Group**	**Properties Heard by Group**	**Tracks Heard by Group**
A	2:15	26 Hz Carrier Frequency, Decreasing Beat Speed	7, 8
B	2:28	40 Hz Carrier Frequency, Decreasing Beat Speed	3, 4
C	2:32	40 Hz Carrier Frequency, Increasing Beat Speed	1, 2
D	2:33	26 Hz Carrier Frequency, Increasing Beat Speed	5, 6
GROUPING III:			
Group Designation	**Average Time Estimate of Group**	**Properties Heard by Group**	**Tracks Heard by Group**
A	2:17	Binaural Beats, Decreasing Beat Speed	4, 8
B	2:22	Binaural Beats, Increasing Beat Speed	2, 6
C	2:25	Monaural Beats, Decreasing Beat Speed	3, 7
D	2:44	Monaural Beats, Increasing Beat Speed	1, 5

Groups A, B, C, and D each represent different individuals who heard different tracks in Groupings I, II, and III.

3.2. Patterns in Group Time Estimates

A pattern emerges between the average time estimates in Grouping I and Grouping II. The following formula holds for the average time estimates of groups A, B, C and D in both Grouping I and Grouping II:

$$(D - A) - (C - B) = 14 \text{ seconds.}$$

While groups A, B, C and D consist of entirely different people in Grouping I and Grouping II, differences in average time estimates between these different groups still lead to a constant of 14 seconds in the formula above. Note, in Table 2, that both Grouping I and Grouping II distinguish groups by the Hz values they heard. There is one salient explanation for the fact that differences in average time estimates in groupings based on Hz values produce a constant of 14 seconds.

A difference of 14 cycles per second exists between the two carrier frequencies, 26 Hz and 40 Hz, used in this experiment. If these frequencies are combined in speakers monaurally or in the human brain binaurally, they create a difference frequency of 14 Hz.

However no individual heard the frequencies combined. In fact the two frequencies were never combined at any time during the experiment, yet the difference frequency manifested itself as a corresponding value in seconds in this analysis. A difference of 14 cycles per second is revealed through a difference in average time estimates of 14 seconds.

It appears that the perception of frequency affects the perception of time such that, in this experiment, difference frequencies were identifiable through differences between average time estimates of groups who heard the two frequencies. In effect, substituting a combination of average time estimates for a combination of average/carrier frequencies has led to a difference, in seconds, representative of the difference frequency that would have been created if the two average/carrier frequencies had actually been combined.

This data points to a new category of difference frequency – one that occurs on a collective level through what is here identified as omnaural perception.

3.3. EEG Analysis

The cases of omnaural perception demonstrated in Grouping I and Grouping II can be examined more closely via basic EEG data from each subject which allows for an analysis of relative neural power to correspond to the analysis of time estimates. Just as time estimates of the groups were averaged and compared, the neural power of the groups is now averaged and compared. A clear pattern emerges between groups that heard a 26 Hz carrier frequency and groups that heard a 40 Hz carrier frequency.

From a primary electrode on the left frontal cortex, this data allows a glimpse into neural reactions that may play a role in omnaural perception. Neural power values were first averaged in six frequency bands over a period of three minutes of audio stimulation for each individual. Then individual data was averaged by group. In Table 3 groups are compared to each other based on their percent deviation, in each frequency band, from the average power values for all subjects during the audio stimulation period. To make the pattern clearer, all negative deviations in neural power have been highlighted.

Table 3. Neural Reactions to Audio Tracks

GROUPING I:									
Group	**Track Properties**	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**Mid Gamma**
A	40 Hz, binaural	-18.54	-36.80	-15.95	-26.05	-24.71	-35.01	-22.22	-20.70
B	26 Hz, binaural	16.86	32.72	14.47	31.68	20.27	44.33	34.37	29.59
C	26 Hz, monaural	11.94	31.26	11.68	19.11	26.03	29.97	13.37	13.41
D	40 Hz, monaural	-10.26	-27.18	-10.21	-24.74	-21.59	-39.29	-25.52	-22.30
GROUPING II:									
Group	**Track Properties**	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**Mid Gamma**
A	26 Hz, decreasing	14.56	14.13	4.16	8.21	6.42	15.51	9.08	8.30
B	40 Hz, decreasing	-17.51	-39.44	-21.52	-33.69	-32.35	-42.33	-30.32	-30.75
C	40 Hz, increasing	-11.29	-24.54	-4.63	-17.10	-13.95	-31.97	-17.42	-12.25
D	26 Hz, increasing	14.23	49.85	22.00	42.58	39.88	58.79	38.67	34.70
GROUPING III:									
Group	**Track Properties**	**Delta**	**Theta**	**Low Alpha**	**High Alpha**	**Low Beta**	**High Beta**	**Low Gamma**	**Mid Gamma**
A	Decreasing, binaural	1.86	-21.93	-14.25	-22.80	-26.43	-27.27	-22.68	-20.72
B	Increasing, binaural	-3.54	17.85	12.78	28.43	21.99	36.59	34.83	29.62
C	Decreasing, monaural	-4.80	-3.37	-3.11	-2.67	0.50	0.44	1.44	-1.72
D	Increasing, monaural	6.48	7.45	4.59	-2.96	3.94	-9.76	-13.59	-7.17

EEG data is calculated as each group's percent deviation from the average neural power values of all subjects, across eight frequency bands, for three minutes. Consistent patterns in neural power correspond to the Hz values heard by constituent groups in Grouping I and Grouping II.

For each group in Grouping I and II, a carrier frequency of 40 Hz corresponds to lower than average neural power in the left frontal cortex, while a carrier frequency of 26 Hz corresponds to higher than average neural power in the left frontal cortex. The pattern extends across every EEG frequency band tested. Grouping III, which does not compare subjects based upon the Hz values they heard, does not show such a clear pattern across each frequency band for the groups involved. Grouping III showed no evidence of omnaural perception.

Grouping I and Grouping II both clearly demonstrated omnaural perception. In each grouping, although groups A, B, C, and D were made up of different individuals, the same trends in neural power emerge when the average power values of the groups are analyzed. This research suggests that the capacity for omnaural perception may correspond to similar neural reactions to carrier frequencies among implicated groups. It also shows that other properties of the tracks (monaural/binaural beats and increasing/decreasing beat speeds) do not correspond to the same clear patterns in average neural power. The carrier frequencies may have an effect which overrides any effects produced by other properties of the tracks.

3.4. Defining Omnaural Perception

Through omnaural perception groups can unknowingly yet accurately measure the difference between two carrier frequencies even when no individual has heard both carrier frequencies. Patterns in averaged time estimates and averaged neural responses indicate that omnaural perception may result from syncing in implicated groups. The two carrier frequencies correspond to patterns in average time estimates, which in turn correspond to patterns in neural reactions, among the groups that heard them.

No individual in this experiment was aware of the group's omnaural perception of a difference frequency. None of the subjects were conscious of making a measurement of frequency at all. Subjects were only asked to make a measurement of time, and the effects of the frequency stimulation on time perception led to the results.

Omnaural perception does not necessarily entail any sort of relationship between time estimates. It merely denotes a relationship between groups that allows for the identification of a difference frequency. It is possible that omnaural perception can be identified in ways that do not involve comparing time estimates. However the discovery of omnaural perception in this experiment was dependent upon the effects of frequency on the perception of time.

3.5. Classifying Omnaural Perception

Three levels of difference frequency perception can now be classified. The primary level is monaural: the sound waves mix before reaching the ears, and the mixing results in constructive and destructive interference which creates the difference frequency. The secondary level is binaural: one sound wave enters one ear and another sound wave enters the other ear. There is no mixing outside of a listener's head. Instead it is thought that the two corresponding signals are mixed in the brain to produce the difference frequency. The tertiary level, discovered in this experiment, is omnaural: no individual hears more than one sound wave. No mixing of any kind occurs. Yet by combining average time estimates from groups who heard different sound waves (mixing the sound waves vicariously, so to speak, via their averaged effects on time perception) the difference frequency can be identified accurately.

This research documents cases of omnaural perception demonstrated by groups composed of individuals who heard either monaural or binaural beat frequency sequences. These sequences of beats, as well as their monaural or binaural properties, varied with each subject. Regardless of the changing beat frequencies or their monaural/binaural properties, each subject heard a constant carrier frequency. Average time estimate data shows that groups who heard different carrier frequencies demonstrated the collective capacity to omnaurally perceive the difference between those two carrier frequencies regardless of the altering series of monaural or binaural difference frequencies heard by each individual.

The EEG data suggests that the monaural or binaural difference frequencies heard by different individuals did not have enough of an effect to offset the effect of the carrier frequencies on averaged neural power in groups. For groups demonstrating omnaural perception, differences in individual beat frequencies did not impede the collective "perception" of the difference between carrier frequencies perhaps because of the overriding effects of the carrier frequencies on brain function.

3.6. The Worldwide Capacity for Omnaural Perception

This experiment identified several groups of Chinese subjects capable of omnaural perception. The prevalence of this capacity among the world's population has yet to be determined.

It should be noted that each of the subjects in this experiment was a native speaker of Mandarin. Mandarin is a tonal language in which changing the pitch of a word can drastically change its meaning. In fact research has shown that speakers of Mandarin and other tonal languages display a higher prevalence of absolute pitch (*i.e.* "perfect pitch") when compared to speakers of non-tonal languages such as English [12]. Speakers of Mandarin appear, in this respect, to be inherently better equipped to correctly identify frequency due to the connections formed in their brains during early development while learning a language dependent on pitch identification.

For this reason it is possible that speakers of tonal languages have a higher probability of demonstrating omnaural perception. More experimentation is needed, using groups from around the world, to test the true scope of omnaural perception. Groups with different native languages should be tested in addition to groups with and without perfect pitch.

3.7. Future Applications

This research has documented cases in which listening to certain frequency combinations led to an increase in the speed of perceived time. Trends illustrated through each grouping can help identify properties of certain frequency combinations that most effectively cause time to appear to move faster.

Several groups demonstrated an increase of over 20% in the perceived rate of time after listening to frequency combinations with certain properties. For instance, the group of subjects who heard a decreasing auditory beat rate through a carrier frequency of 26 Hz perceived time, on average, as being 25% faster than it really was.

This research suggests that certain frequency combinations can be used in planes, trains, buses, or cars to make travel time appear faster. They can be used in waiting rooms or in long lines to make people feel as if the wait time has been reduced. Web pages and computer games can use frequency combinations to make loading time appear shorter.

The ability to alter the perception of time with frequency combinations may also be influenced by the native language of the listener. Future experiments on native non-tonal language speakers are necessary. It may be the case that the capacity for perfect pitch entails certain recognizable effects of frequency on time perception. If so, and if the tonal language speakers in this experiment were more likely to possess perfect pitch due to their native language, then future applications may have to be tailored to groups on a tonal/nontonal native language basis.

4. Conclusion

This experiment revealed the phenomenon of omnaural perception whereby difference frequencies are identifiable by groups in which it is completely impossible for any individual to make the identification. Groups displayed the capacity for accurate measurement of the difference between two carrier frequencies when no individual in each group heard more than one carrier frequency, and no individual was allowed to communicate with any other individual. Furthermore groups demonstrated the ability to accurately measure the difference between two carrier frequencies when no individual was conscious of making a measurement of frequency; subjects were only asked to make a measurement of time.

The EEG data identifies a pattern in neural reactions that corresponds to omnaural perception. It suggests that the two carrier frequencies had opposing effects on relative neural power in the left frontal cortex. The pattern was pronounced in groups that demonstrated omnaural perception and absent in groups that did not.

The theoretical ramifications of omnaural perception suggest new classifications for group wisdom and difference frequency perception. Indirect applications of this research involve using frequency combinations to cause time to appear to move more quickly for targeted groups.

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