Tempo Change Aftereffects After Habituation To Risset Accelerandi

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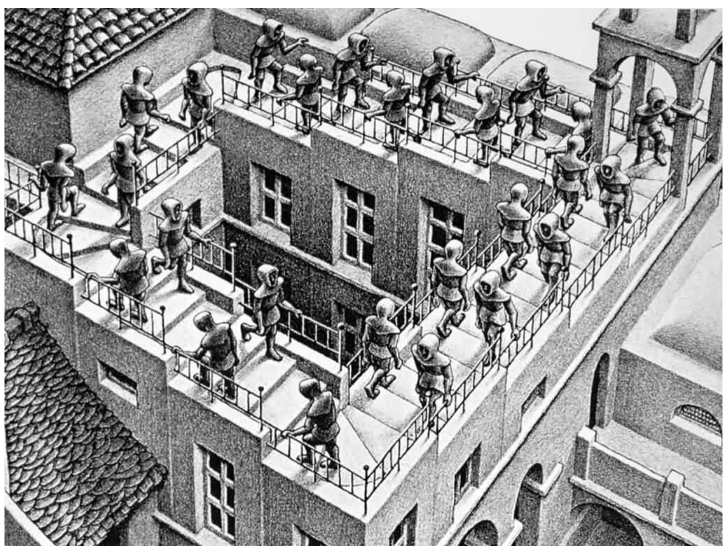

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Abstract

The motion aftereffect, or waterfall illusion, is the modification of motion perception after extended observation of a moving stimulus. The opponent proces model provides means of explaining this illusion. To assess the existence of a similar illusion within the domain of tempo perception, Risset accelerandi (rhythms that change tempo endlessly) were constructed. After being exposed to a prime-rhythm increasing or decreasing in tempo, participants were asked to judge a probe-rhythm with a small change in tempo. Results showed an increased tendency to perceive a deceleration after an accelerating prime-rhythm, confirming the presence of a tempo change aftereffect. After a decelerating prime-rhythm, no such significant tendency was found.

Keywords

Motion aftereffect, tempo change, rhythm, Risset accelerando, opponent proces model

I. INTRODUCTION

A. Visual motion aftereffect

After Aristotle first described the visual motion aftereffect (MAE[1]) in his Parva Naturalia (Ross, 1931), it fell into oblivion. The reason for this can, according to Mather, Verstraten and Anstis (1998), be found in the fact that the MAE wasn't described in Ptolemy's seminal work "Optics", to which many later researchers referred to. Two millennia later though, R. Addams (1834) picked up the phenomenon again by describing it vividly when he watched a waterfall at Foyers, Scotland (hence the more popular name for MAE: the Waterfall illusion).

> *Having steadfastly looked for a few seconds at a particular part of the cascade, admiring the confluence and decussation of the currents forming the liquid drapery of waters, and then suddenly directed my eyes to the left, to observe the face of the sombre age-worn rocks immediately contiguous to the waterfall, I saw the rocky surface as if in motion upwards, and with*

[1] The visual motion aftereffect is most often abbreviated to MAE. Although this leaves the sensory domain being unspecified and therefore ambiguous, I shall also use this abbreviation and use the much used aMAE to denote auditory motion aftereffects throughout this thesis.

an apparent velocity equal to that of the descending water, which the moment before had prepared my eyes to behold that singular deception.

— Robert Addams

Thus the MAE is the illusion that after being exposed to a moving stimulus, movement in the opposite direction is perceived. For instance, shortly after a long train travel, a train station might seem to move backwards—assuming that you were looking out of the window, facing the direction of movement. If you are sitting in an office chair while reading this, you could try spinning around fast for a while, to see the world spinning the other way around when you stop.

In the sixties, Barlow and Hill (1963) found that motion-sensitive ganglion cells in the retina of rabbits start firing when confronted with motion. This firing gradually reduces, so that it drops below baseline level when motion stops. This was the first evidence for the seminal opponent process model. Since then, the MAE has been a prolific field of research, spawning behavioural studies (Houghton, Macken & Jones, 2003; Currana & Benton, 2006; Falkenberg & Bex, 2007; Xiao & Güntürkün, 2008), fMRI (Taylor et al., 2000; Huk, Ress & Heeger, 2003; Seiffert et al., 2003), EEG (Winawer, Huk & Boroditsky, 2008), MEG (Tikhonov et al., 2007) and PET experiments (Hautzel, 2000).

The opponent process model models motion perception and was first proposed by Sutherland (1961) two years earlier, albeit slightly different. Its architecture can be seen in Figure 1, in which the squares are units sensing a direction, an arrow excites and a dot inhibits. Similar models have been used to explain a variety of phenomena, including colour perception and even drug addiction. It has come to be the standard explanation of the MAE. Several additions have been made to it, most noteworthy its expansion to include a second dimension (Wilson, 1992).

The model consists of two layers: the motion sensor layer and the opponent energy layer. The units in the motion sensor layer provide evidence for and against a certain percept. For upward motion to be detected, for instance, the upward sensor excites the opponent energy unit representing upward motion, while the downward sensor neither excites or inhibits. Instead, it remains at resting level, since there is no downward motion to detect. The net result of this is excitation in the opponent energy unit for upward motion. If this excitation is higher than a certain threshold, upwards

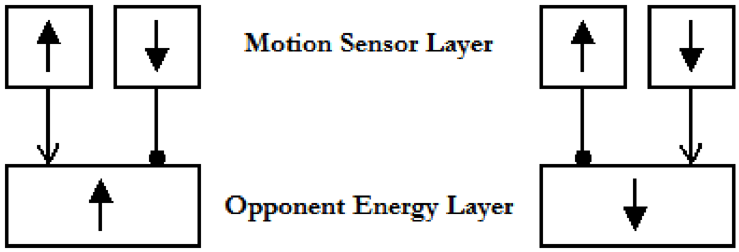

Figure 1: Diagram of the opponent-process model. The motion sensor layer passes on evidence for or against a percept (in this case upward and downward motion). The opponent energy layer combines this information to decide on the presence or absence of this percept.

movement is perceived[2].

In the opponent proces model, a MAE is the effect of adaptation in the sensor layer. Figure 2 visualizes the process behind it. The adaptation to upward motion in the sensor layer causes the sensor unit and therefore the opponent energy unit for upward motion to have a lower output. It also excites the opponent energy unit for downward motion, because it is now inhibited even less by the upward sensor. If this excitation is above threshold, a MAE is perceived[3]. In reality, adaptation also occurs in the opponent energy layer, but this does not contribute to the perception of MAEs; only the sensor layer does.

Early reports pose the idea that the adaptation is the result of mental fatigue (Kohler & Wallach, 1944). According to this idea, neurons are incapable of producing neurotransmitter at high concentrations for long periods of time, therefore somehow satiating them. This has been rejected for several reasons, one of them being that aftereffects can actually result after very short adaptation, which is in contradiction with neurons needing a long period of time to become satiated.

Three ideas took its place as explanations for the MAE: error-correcting, coding optimization and calibration. Ullman and Schechtman (1982) pro-

[2]The choice for this architecture has implications on the architecture of the brain (if it should have high cognitive fidelity): it assumes that in the brain there are distinct areas that work in the same way as the two layers in the model.

[3]Note the verbal nature of this explanation: it is not explained how exactly and to what degree this adaptation causes activation at the upward sensor to decrease.

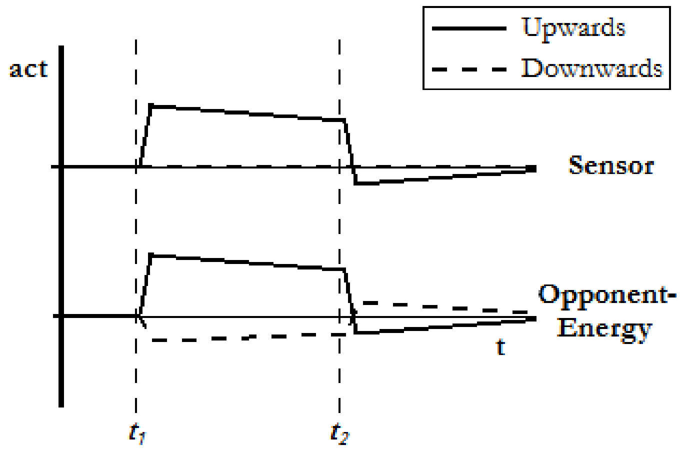

Figure 2: Explanation of MAE in the opponent-process model. Between t_1 and t_2, upward motion is present. Activation of sensor and opponent energy units for both upward and downward motion are plotted. If the activation of the downward motion unit in the opponent energy is high enough immediately after t_2, a MAE is observed.

posed the first idea, a mechanism that detects and restores errors that arise frequently in the optical system, like black spots and fringes. According to the coding optimization explanation, the brain lacks size or complexity to perfectly cope with all problems that perception poses. To be able to cope with these problems near perfectly, their solutions should be optimally coded. The calibration explanation on the other hand, is concerned with mechanisms that dynamically modify neurons so that the outcome of perception is calibrated to changing circumstances. The general goal of these mechanisms is to manage a system that works well in different surroundings, because an organism often has to function while moving in a changing environment. A similar recalibration mechanism exists for the perception of light and dark, making it possible for humans to see well in bright sunlight, lit rooms and dark nights[4]. It has to be stressed that all three mechanisms can be at work simultaneously, for they don't exclude each other.

MAEs occur as a side effect of motion perception, not as a desirable effect. They have no practical use but instead are misperceptions, illusions.

[4]This is quite remarkable, for the difference in illuminance between the brightest sunlight (120000 lux) and a moonless overcast night (0.0001 lux) is enormous

Human motion perception would be more efficient if MAEs were avoided. A calibrating mechanism functions by tuning perception so that static objects can be perceived as such when the agent itself is in motion. This is a form of adaptation to surroundings, for it is easier to make judgments and manipulations about a static image. If, however, the mechanism takes a significant amount of time to (re)calibrate, the MAE becomes its unintended, undesired side effect.

B. Auditory motion aftereffects

Compared to the visual motion aftereffect, less research has been done on aftereffects for other sensory modalities; research seems to be restricted to the visual area. When auditory perception is considered, it is often examined in combination with visual MAE (Dong, Swindale & Cynader, 1999; Hong & Papathomas, 2006). Yet, some of the different aspects of auditory perception have been researched independently to see if an auditory motion aftereffect (aMAE) occurs for that particular aspect. For example, pitch perception has proven to be subject to aMAE by Kayahara (1998; 2001) and aMAEs for amplitude have been studied by Reinhardt-Rutland (1995) with positive results. Also, Grantham (1989) found the existence of aMAEs for location experimentally. In the latter, participants listened to auditory stimuli moving in one direction in space, after which they reported how they perceived a spatially stationary stimulus. Practical uses of the mechanisms behind these aMAEs are hard to pinpoint, compared to the mechanisms behind the MAE. An organism might yield a benefit from adapting to a certain tempo and the way it changes, for instance a heart beat, footsteps or any interaction with music. Also, time perception in general is closely linked to this adaptation.

Since aMAEs are reported reliably, any self-respecting modeler of auditory perception needs to explain them. The opponent process model is a good example of such a model, because it explains the MAE, the visual analogue of aMAEs. It has proven to be a simple but effective—and therefore influential—model for many other psychological phenomena (Mather, Verstraten & Anstis, 1998). Lately, it has even been used to explain auditory perception of location (Phillips, Carmichael & Hall, 2006). Applying the same model to different aspects of perception is inherently coherent, consistent and logical from an evolutionary perspective. For these reasons, the opponent process model is used in this thesis to explain auditory perception.

Employing the opponent process model in this setting implies that aMAEs are an intrinsic aspect of auditory perception. This notion is put to the test by looking for an aftereffect more specifically in the domain of tempo perception in the experiment presented in this paper. This tempo change aftereffect shall be abbreviated to tcAE and defined as perceiving tempo change in the opposite direction after being exposed to a rhythmic stimulus with a (gradual) tempo change—notice the resemblance with the definition of the MAE. A simple example of a tcAE would be perceiving a rhythm with a stable tempo as slowing down after being exposed to a rhythm that increased in tempo.

C. Risset accelerandi

To induce a tcAE, a rhythm that speeds up or slows down is needed for habituation purposes. Two constraints arise from this necessity. The first constraint is that both the habituation rhythm and the rhythm probing the participant's perception directly after it should have the same mean tempo among the different possible types of habituation rhythms for this experiment to be able to generalize. More specifically, a rhythm that serves as habituation to a tempo increase should have the same mean tempo as a rhythm that serves to habituate to a tempo decrease and should preferably also end at the same tempo, ensuring that all probing rhythms can follow smoothly at similar tempi. The second constraint concerns the boundedness of tempo perception. A rhythm can be sped up to the point that it becomes noise and slowed down to being so inert that it hardly perceived as being a rhythm with a tempo[5]. In an experimental setting having to do with tempo, this would be most undesirable. A rhythm that satisfies these constraints is the Risset accelerando. The Risset accelerando is based on its analogue in the frequency domain called the Shepard scale, which shall be described briefly before the accelerando is explained.

In the sixties, cognitive scientist Roger Shepard (1964)—and later French composer and Bell Labs co-worker Jean-Claude Risset (1986)—described a new kind of tone. A Shepard tone is not just a normal, single tone; it is instead defined by its base tone plus a number of its octaves superposed on it. The amplitudes of these octave tones are a Gaussian function of the distance in frequency to that of the base tone, making the base tone loudest, the neighbouring octaves slightly less intense, their neighbours even softer, and so further.

If you increase the frequency of the base tone of a Shepard tone and its surrounding octaves, while still computing the amplitudes of all these tones using the original Gaussian function, an auditory illusion of an ever

[5] A bell being struck every hour would not be considered a rhythm by the majority of people.

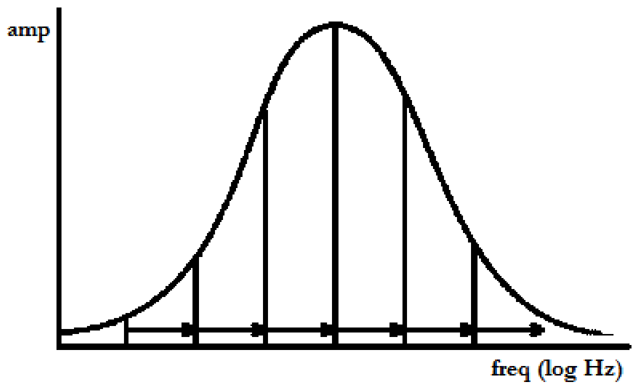

Figure 3: Typical Shepard tone, consisting of six octaves with a Gaussian filter over their amplitudes.

rising tone appears. Decreasing the frequency will result in an ever falling tone, analogously. This process is illustrated in Figure 3, in which a Shepard tone is represented by vertical lines distributed evenly over the frequency axis, bounded in amplitude by the Gaussian envelope. When shifting these lines to the right, the same pattern of lines eventually reappears, making the process of rising a Shepard tone in frequency periodical. Applied in steps, this process of rising Shepard tones is called the Shepard scale; applied continuously, it is called the Risset glissando. The illusion arises because the human ear tends to focus a specific tone—or a vertical line in Figure 3—that continues far beyond the length of one octave, while the combination of tones as a whole is periodic with phases of one octave.

This auditory illusion can be compared to its visual counterparts, like the Penrose stairs, Escher's waterfall or the Archimedes screw. In the Penrose stairs for instance, which can be seen in the figure on the title page, the four stairs in each wind direction make up a closed circle. Walking along it is a periodic movement; certainly, you will never get "upstairs". This is the paradox you also find in Shepard scales: every tone you focus on moves upwards, still you will never get to a higher average frequency.

Later on, Risset—together with K. Knowlton, also from Bell Labs—discovered that the mechanism used in the Risset glissando can also be applied to tempi, thus creating a rhythm that seems to slow down or speed up endlessly: the Risset accelerando (Risset, 1989). In the Risset accelerando, rhythms that are twice as slow or fast are added to a base rhythm, similar to the way the base tone is supported by its neighbour octaves in the glissando. Also, the amplitude of every single rhythm is a function of its distance in tempo from the base rhythm. Listening to a Risset accelerando creates an illusion of a rhythm that seems to speeds up or slows down endlessly. This makes it possible to keep rhythms playing at comfortable, salient tempi for longer periods of time. Rhythms for probing purposes that follow directly can have the same tempo, independent of the direction of tempo change in the Risset accelerando. Because Risset accelerandi hereby satisfy the two constraints put forward earlier, they are used as habituation rhythms in this thesis' experiment.

Its hypothesis is that the tcAE exists and that the opponent-process model[6]describes it, as it describes the visual motion aftereffect. More specific, the prime condition should have a negative effect on perceived tempo change, the probe condition a positive effect. For example, within the same prime condition, a probe with increasing tempo should be perceived as more increasing in tempo than a probe with no tempo change (positive effect). Also, a similar probe should be perceived less increasing after a prime with increasing tempo than a prime with no tempo change (negative effect). In further analysis, the seperate probe conditions after a neutral prime can be used as a fixed contrast for similar probes after other primes to be compared with, because it is a type of baseline measure. The hypotheses are visualized in Figure 4.

To help decide on the exact length, tempo acceleration, timbre and other attributes of the stimuli, a pilot session was done. This resulted in a set of parameters that were used to generate stimuli. Also, findings from past experiments were useful. For example, Grantham (1989; 1998) notes that aMAEs in general are very short, in the order of seconds after adaptation ends, so preferably the rhythm used for assessing the presence of a tcAE is short. He also shows that aMAEs are stronger for broadband sounds than for pure tones (Grantham, 1989). Later studies show a favour for low frequencies (Grantham, 1998; Dong, Swindale, Zakarauskas, Hayward & Cynader, 2000). The duration of the visual MAE is proportional to the square root of adaptation time up to 90 seconds (Hershenson, 1993). Also, the greatest effects in MAE are seen when the test stimulus most closely resembles the adaptation stimulus (Mather, Verstraten & Anstis, 1998). The sound sample used to make these rhythms was one of a cowbell being struck, because in succession this sounds natural and salient. Low freq, not pure tone.

[6]Or an alternative model with at least equal explanatory power concerning aftereffects.

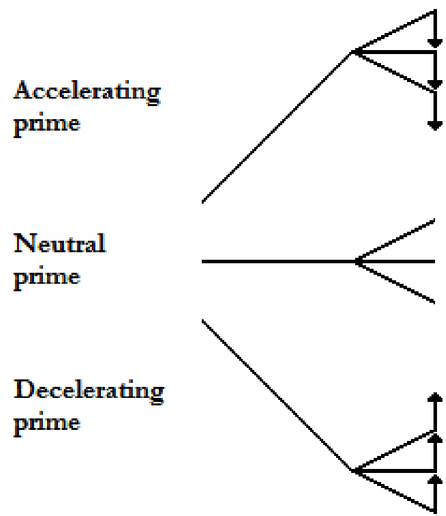

Figure 4: Visualization of the hypotheses. After an accelerating prime condition, a shift towards the perception of a deceleration is expected; after a decelerating prime condition, a shift towards the perception of an acceleration is expected.

II. METHODS

A. Participants

Participants were 18 adults, 8 female, average age 25.2±4.5 years, either studying or working at the Radboud University, Nijmegen. On average, they listened to music for 2.9±2.1 hours on a daily basis. 6 participants had no musical expertise, 8 played an instrument at amateur level, 3 at professional level and 1 was a DJ. None of them had significant problems hearing. There was no reward for participation.

B. Materials

The stimuli in the experiment were divided in two parts: a prime-rhythm and a probe-rhythm (simply prime and probe from now on). The transition between both parts was fluent, as such that there was no sudden jump in tempo between the two. There were 9 different stimuli, based on 3 different primes—accelerating, neutral and decelerating—combined with 3 different probes. An abstract example of such a stimulus is shown in Figure 5. In this figure, at least three different rhythms with distinct tempi and at distinct amplitude levels can be clearly distinguished.

A prime existed, regardless of the type, of a 20 second Risset accelerando with an average weighted tempo of 120 BPM. Here, average weighted tempo means the weighted sum over the tempi of the individual rhythms the Risset accelerando is made up of, divided by the number of those rhythms. The sum is weighted by amplitude, so that a rhythm with a high amplitude contributes more to the sum than one with a low amplitude. The timespan of 20 seconds fluctuates slightly—in the order of tens of milliseconds—over the different types of prime, the neutral prime being shorter. Figure 6 depicts the progression of the tempi and amplitude of the seperate rhythms of an accelerating prime. In this figure, each rhythm quadruples in tempo, unless the rhythm already had a high tempo, in which case it fades away.

$$\nu_{i,\pm} = \begin{cases} \nu_0 \cdot 2^{\pm t_i/10} & for \quad t \leq t_{tr} \\ \nu_0 \cdot \sigma^{(\pm t_i - t_{tr})/6} & for \quad t > t_{tr} \end{cases} \tag{1}$$

The probe is a 6 second rhythm[7] that starts at an average tempo of 120 BPM. The duration of the probe is dependant on the type of probe, but the difference in duration is very small (0.01 seconds). The amplitudes of the seperate rhythms stay the same, to prevent participants from being able

[7]The length of a probe is 33 samples, regardless of the type.

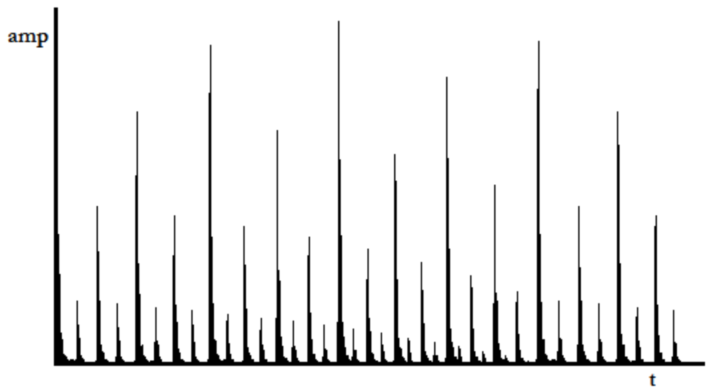

Figure 5: This plot shows part of an accelerating Risset accelerando. The sample is visible as a spike, its amplitude as the height of this spiket. Inherent features of accelerating Risset accelerandi can be observed. For instance, the samples generally get closer to each other and decrease in amplitude over time: they speed up while fading out.

to distinguish a neutral probe from other probes because of the absence of an amplitude shift. Figure 6 depicts a decelerating probe. In this figure, the average tempo drops to 116 BPM. Thus, the tempo of a rhythm at a given time is given by the latter part of Equation (1), in which ν_0 is the tempo at $t = 0$, $\sigma (= {}^{120}/_{116})$ is the acceleration speed and t_{tr} is the transition time. The equivalent for a decelerating prime is obtained by using $-t$ instead of t, hence the $\pm$-sign; in a neutral prime the tempo is unchanged.

C. Design

A repeated measures ANOVA design was used to measure the effect of the prime condition and the probe condition on the perceived tempo change. When necessary, T-tests were done to compare seperate probe conditions after a neutral prime (fixed contrasts) with similar probes after other type of primes.

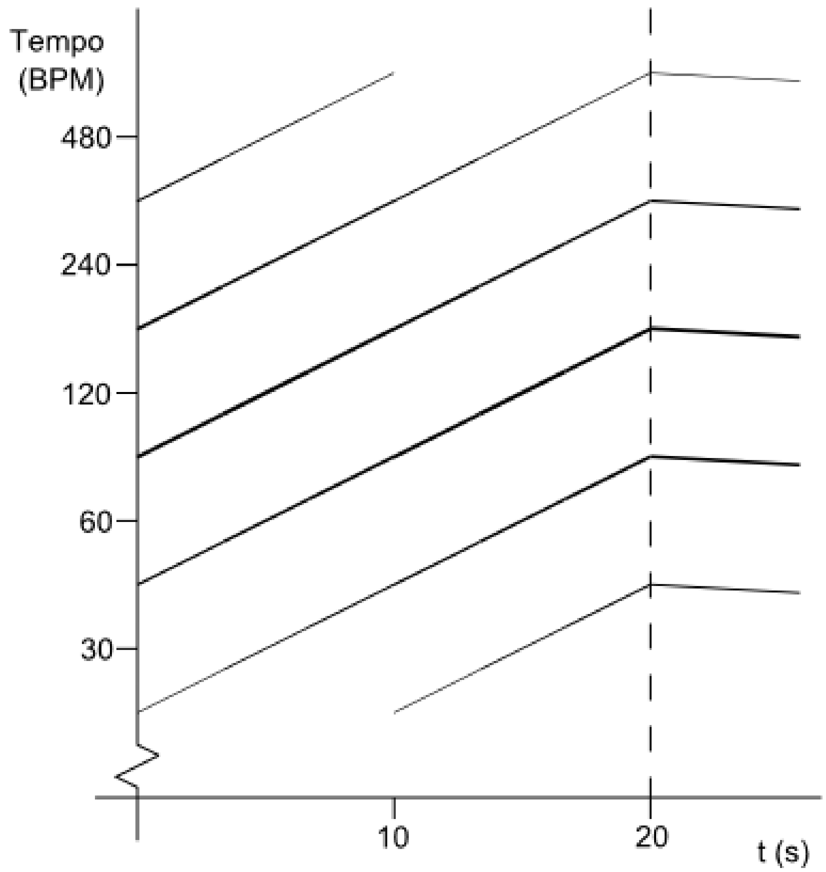

Figure 6: Specifics for a stimulus with accelerating prime and decelerating probe. Time is plotted on the x-axis, tempo on the y-axis and amplitude is represented by the thickness of the line. The seperate rhythms start at an average weighted tempo of 120 BPM, after which the seperate rhythms speed up and fade out for 20 seconds. Then the probe rhythm starts, making the average tempo drop to 116 BPM in 6 seconds.

D. Procedure

Stimuli were presented to the participant using a Power Mac G5 and Sony headphones. There was little to no background noise in the experimental environment, since this environment was the soundproof studio of the Music Mind Machine group at the Radboud University, Nijmegen. The user interface consisted mainly of three buttons that were only activated when the participant had to give a response and a graphical picture of a note, which was visible when the rhythm was heard and changed when the probe started. Simple instructions were implemented in this user interface, in order to lead the participant through the different phases of the experiment. Participants were tested individually.

The main experiment was divided into three blocks varying in the prime that was presented. One block had an accelerating prime, one a neutral prime and one a decelerating prime. The order of the blocks was counterbalanced. Within each block were 15 trials, 5 for each probe (5 accelerating, 5 neutral and 5 decelerating probes). The order of the trials was randomized. A visual cue, the note mentioned earlier, was presented to the participant every time the probe started. The participant could respond directly after the probe ended, by clicking the button on the screen representing the participant's response (either acceleration, no tempo change or deceleration).

Before the main experiment, participants filled in a one-paged questionnaire, containing questions about hearing problems and music listening habits. They also got instructions about the experiment and a short practice session. This practice session consisted of 3 trials (with probes that were easier to judge than the probes used in the main experiment. Participants were explicitly instructed to listen to the prime and to indicate how they perceived the tempo change of the probe, from when it started to when it ended. There was room for a break after the practice session and after each block in the main experiment. Afterwards, participants were debriefed about the purpose of the experiment.

III. RESULTS AND DISCUSSION

A. Results

Per participant, averages were computed for every combination of prime and probe, resulting in 9 averages. For this computation, a response "neutral" has value 0, a response "accelerate" has value 1 and a response "decelerate" has value 1. Figure 7 shows the means and standard deviations of the

Prime		Probe: Accelerating	Neutral	Decelerating	Total
Accelerating	$\overline{x}$	0.078***	-0.256***	-0.611	-0.263
	σ	0.239	0.246	0.385	0.407
Neutral	$\overline{x}$	0.633	0.078	-0.700	0.004
	σ	0.365	0.239	0.424	0.651
Decelerating	$\overline{x}$	0.156**	-0.100	-0.311**	-0.085
	σ	0.473	0.338	0.249	0.407
Total	$\overline{x}$	0.289	-0.093	-0.541	-0.115
	σ	0.441	0.305	0.392	0.401

Table 1: Means and standard deviations of the participants' average responses. Remember that a value of 1 means purely "accelerate" responses, while -1 means purely "decelerate" responses. Significant differences with the neutral prime within the same probe condition are denoted with ** ($p < .01$) and *** ($p < .001$). The other differences were not significant.

participants' average responses, Table 1 summarizes this data and gives a significance measure.

A repeated measures ANOVA showed that there were significant effects for prime, $F(2, 17) = 14.7$, $p < .001$, and probe, $F(2, 17) = 35.7$, $p < .001$. There was a significant interaction between prime and probe, $F(4, 17) = 6.8$, $p < .01$.

T-tests with fixed contrasts (comparison with the neutral prime) showed that there were significant effects for prime within the same probe, as indicated in Table 1. For instance, responses differed significantly between accelerating prime and neutral prime for accelerating probe, $t(17) = -6.7$, $p < .001$, and neutral probe, $t(17) = -4.9$, $p < .001$. In this, probes were perceived as more decelerating after the accelerating prime, indicating a tcAE. Exceptions to this significance are the decelerating probe after an accelerating prime, $t(17) = 0.7, p = .521$, and the neutral prime after a decelerating prime, $t(17) = 1.7, p = .104$. Simple post-hoc t-tests also showed that there were significant effects for probe within the same prime, with the exception of the difference between neutral and decelerating probes after a decelerating prime, $t(17) = 2.1$, $p = .053$.

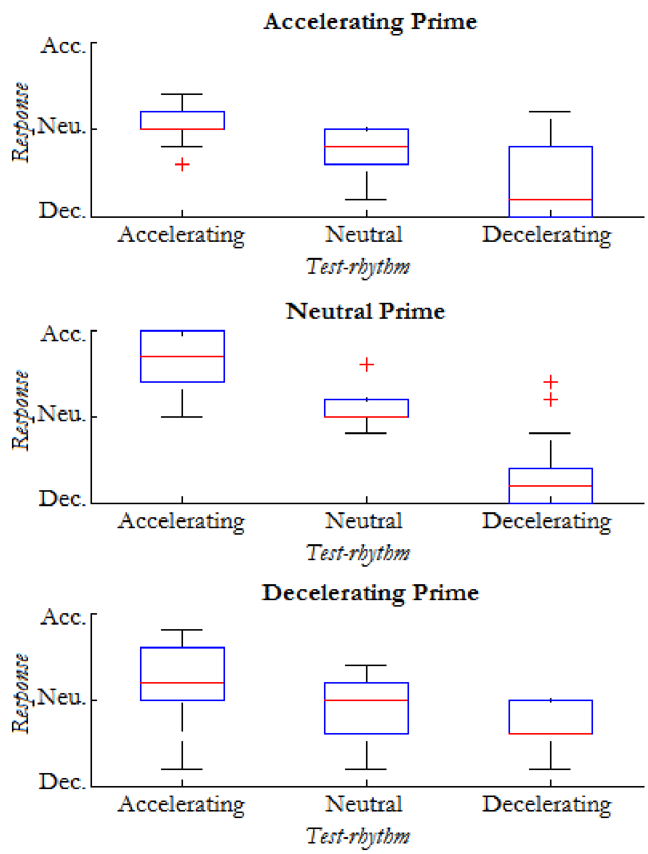

Figure 7: Box plots showing the response distribution for every combination of prime and probe. Per box, smallest non-outlier observation (in black), first quartile (in blue), median (in red), third quartile (in blue), largest non-outlier observation (in black) and outliers (red plusses) are shown.

B. Discussion

The results of this experiment tell different stories. First, the results for the neutral condition, the condition with a prime increasing in tempo and the condition with a prime decreasing in tempo shall be discussed respectively. Then, future research possibilities are proposed

The results for the neutral condition—where a rhythm with no tempo change was used as prime—are as expected: participants perceive a probe changing tempo significantly more often when there is a change of tempo in that direction. On the other hand, not every tempo change is perceived. This is also conform expectations, because a just noticeable tempo change was used.

The results for the condition with a prime increasing in tempo also confirm the hypothesis. Participants respond clearly different from the neutral condition. There is a tendency to perceive rhythms having a tempo decrease, even when there is none, which is in agreement with the hypothesis of this thesis and indicates that a tcAE is perceived.

The results for the condition with a prime decreasing in tempo show a different pattern that was not predicted. According to the hypothesis, a tendency to perceive increasing tempo is expected. Yet, in this setting, this tendency is absent. The relatively large variance within the participants' responses is also of importance.

One explanation for this absence is that, after being exposed to a tempo decrease, the rate of tempo change is too small to be reliably perceived. This is noteworthy, because it is not in the condition with a tempo increase as prime, which can be seen as its direct counterpart and indicates that perception of tempo change is asymmetric. Evidence for an asymmetry in tempo change perception has been found more often. Repp and Wang, for instance, found that decelerations are easier to detect than accelerations (Repp, 2001; Wang, 1984). A possible source for this asymmetry is speech. The fact that accelerations and decelerations are perceived differently potentially contributes to the observation made in this experiment that a small tempo change is reliably perceived after an increasing tempo but not after a decreasing tempo.

Another explanation is that the stimuli themselves induce asymmetric behaviour. The plots in Figure 5 show that the accelerando and the decelerando are nonlinear. Because of this, decelerandi approached the probe more smoothly. This smooth transition could be the source of uncertainty in participants, since it is very well possible that making decisions about change of tempo is complicated by a smooth transition. In future work, it should be investigated to make transitions equally smooth for both conditions, so that this influence is nullified.

The significant interaction that was found is at least partly due to the small number (3) of possible responses. The fact that other responses were impossible entails a ceiling effect and a general difficulty of finding a complete normal distribution of responses. This lack of specificity is probably cause of a portion of the interaction between prime and probe.

Since this research was kept rather basic by only presenting participants with one rate of tempo change (both in primes and probes), but still reached significant effects, it would be fruitful to expand it to a more elaborate experiment. When a larger number of tempo change rates are presented, it is possible to learn more of characteristics of the tcAE itself. Furthermore, perception of tempo change has proven to be personal and thus different from participant to participant: results from this experiment showed that some participants could recognize change with a high success rate while others performed at chance level. In other words, every participant has its own just noticeable difference (JND) for tempo change. With the addition of more tempo change rates to this experimental setup, more participants' JNDs will be within its scope. This is desirable, for it is at the JND that the biggest effect is found—easier to perceive than the JND results in purely correct behaviour, while more difficult to perceive results in pure guessing.

It is also possible to vary different aspects of the prime, the probe and the sample sound used. Some examples of parameters that can be varied for prime and probe are their duration, tempo change rate, average tempo and complexity. The used sample can be varied in frequency or distribution of frequencies and duration. It would also be interesting to see alternative methods to the Risset accelerando at work. For rhythms of short duration, it could be a consideration to use normal accelerandi, but this could still lead to trouble regarding symmetry: consider an experiment with an accelerating and a decelerating prime condition which accelerate and decelerate normally. Then, if average tempo and tempo change rate are equal, these conditions will conclude at different tempi, the accelerating prime reaching a higher tempo than the decelerating one. With this in mind, it becomes impossible to have the same probe for both of these prime conditions—without losing a smooth transition. An alternative method should, in my view, avoid or solve this problem.

Besides aftereffects for tempo change, there are other aspects of hearing that might be subject to aftereffects. It would be interesting to test for these aspects as well, to see if the idea that these effects are intrinsic to human perception holds. If so, one would aspect aftereffects for change of location of sound. For instance, a continuous movement of sound from left to right would result in a stationary sound being perceived as moving to the left. This azimuth variation can be easily created by changing the panning of speakers. Also, aftereffects for continuous change in timbre, frequency, loudness and other properties of sound are worth researching.

At the moment, the opponent-process model explains aftereffects, but only verbally by stating that there is adaptation at the sensor layer. A more formal model would be preferable, for example a neural or Bayesian network or a mathematical model. In order for these to be of any use, more information should be available on the process of aftereffects and that's where the aforementioned research proposals come to aid. These formal models are almost guaranteed to give insights in human perception and could even spark new methods in artificial perception.

IV. SUMMARY AND CONCLUSION

The opponent-process model for visual perception has proven to provide an explanation for the MAE. It was assumed that this model could potentially model other domains of perception and explain their aftereffects. Under this assumption, an experiment was run to find out if there was an aftereffect for tempo change. In this experiment, participants were presented with a prime and a probe, both either accelerating, neutral or decelerating, after which the participants indicated if they perceived the probe as accelerating, neutral or decelerating. When participants perceive probes as accelerating significantly more than they do after a decelerating prime and vice versa, a tcAE is present. If this tcAE, defined as the perception of tempo change in the opposite direction after exposure to a rhythmic stimulus with a (gradual) tempo change, can not be found, the proposition should be revised. Yet, results of the experiment showed the presence of such tcAEs after an accelerating prime, which is consistent with the aforementioned assumption. Mixed results were found after a decelerating prime. Reasons for this can be that perception of rhythm is asymmetric and therefore different after acceleration than after deceleration. Also, the nature of the used Risset accelerandi were a potential source for these different results. Argued was that the transition from prime to probe was smoother after a decelerating prime.

It was proposed to expand the experiment by presenting participants with a wider variety of tempo change rates for prime and probe, so that properties of the tcAE are exposed. Additionally, other parameters of the rhythms could be varied as well, to investigate what influence they have on the strength and nature of the aftereffect. This could be linked to further research on aftereffects in other properties of the auditory domain, like location and timbre. In total, the information from this research can be used to model aftereffects and perception more formally by expanding the opponent-process model, which in its current form only verbally explains aftereffects.

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