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The octave illusion (Deutsch, 1974) has been the subject of several lines of investigation, including its value in assessing patterns of cerebral dominance, and its role as an illusory conjunction of *what* and *where* information by the auditory system. The paper by Oehler and Reuter shows that perception of the illusion correlates strongly with findings from the tapping task described by Kopiez, Galley, and Lehmann (2010). In so doing, it provides important information for understanding the basis of this illusion, while at the same time displaying the value of this tapping task as an indicator of cerebral dominance.

The study reported in the present paper is unique in that it carefully replicates the stimulus parameters used by Deutsch (1974, 1978, 1980, 1981, 1983, 1988). More specifically, there were no amplitude drops at the transitions between the tones in the pattern, and phase continuity was preserved at the transitions. Most studies that were later carried out by others on this effect either did not preserve phase continuity (and so imported clicks at the transitions) or imposed rise-fall times on the tones. While there has been no formal study to determine whether these variants are associated with a weaker or less consistent octave illusion, it is my informal impression that this is the case. Also importantly, the present authors were careful to use the same tone duration, amplitude, and length of pattern as in the original study, and to follow the same procedure as was used by Deutsch (1983) to determine the subjects' percepts.

In the original study by Deutsch (1974) perception of the octave illusion was found to correlate with handedness in two ways. First, right-handers tended more than left-handers to obtain a clear illusion consisting of a single high tone in one ear that alternated with a single low tone in the other ear. In comparison, left-handers tended more than right-handers to obtain different, mostly complex, percepts. A second finding produced by Deutsch (1974), which was later replicated in a large-scale study by Deutsch (1983), concerns the patterns of localization of the high and low tones in the illusion: Right-handers tended strongly to hear the high tone on the right and the low tone on the left, while mixed-handers were more varied in their localization patterns, and left-handers were still more varied. The present study replicated and extended both these findings using the tapping task of Kopiez et al (2010).

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One difference between the study of Deutsch (1983) and the present one is that the former study also evaluated the effect of familial handedness background on perception of the illusion. Earlier work had indicated that a familial background that includes left-handers may be associated with different patterns of cerebral dominance than a familial background consisting only of right-handers. Right-handers with left-handed relatives have been found to have a greater probability of recovering from aphasia (Luria, 1969; Subirana, 1958) and also a greater probability of crossed aphasia (Ettlinger, Jackson, & Zangwill, 1956) compared with those without left-handed relatives. In addition, studies of normal subjects have found that those with left-handed relatives performed differently on various tasks than did those with only right-handed relatives (see, for example, Varney & Benton, 1975; Zurif & Bryden, 1969). As expected from these studies, Deutsch (1983) found that, for right-handers, mixed-handers, and left-handers taken separately, the tendency to hear the high tone in the right ear and the low tone in the left ear was stronger among those with only right-handed parents and siblings than among those with a left- or mixed-handed parent or sibling. It will be interesting to determine whether a difference in performance on the tapping task might also emerge between those with and without left-handers in their immediate family.

Given the strong handedness correlates that were obtained, Deutsch (1983) proposed that perception of the octave illusion might serve as a reliable indicator of the direction of cerebral dominance in a given individual – a hypothesis that is strengthened by the present findings. Recently, direct evidence in support of this hypothesis was obtained by Ferrier, Huiskamp, Alpherts, Henthorn and Deutsch (in preparation). We tested 17 patients who were scheduled to undergo the Wada test to evaluate their patterns of cerebral dominance in preparation for brain surgery. (In the Wada test, an anaesthetic is injected into the carotid artery on one side. If this produces loss of speech function, speech is assumed to be represented on the side ipsilateral to the injection.) Based on their responses to a handedness inventory, the subjects were mostly right-handers, but included four left- or mixed-handers, and one right-hander who was later found on the Wada test to have language represented in the right hemisphere. As predicted, all subjects heard the octave illusion with the high tone on the side contralateral to the hemisphere that was later found on the Wada test to be dominant for speech. This result indicates that the octave illusion might serve as a useful, simple, and noninvasive diagnostic tool in evaluating lateralization patterns in patients who are candidates for brain surgery. This is potentially of clinical importance since other noninvasive measures, such as fMRI, have been shown to correlate only imperfectly with the results of the Wada test (see, for example, Dym, Burns, Freeman, & Lipton, 2011).

The physiological bases of the correlations between percepts of the octave illusion and patterns of cerebral dominance have yet to be determined. Deutsch (1975) proposed a model of the illusion in terms of the combined operation of separate decision mechanisms, one determining what pitch is heard, and the other determining perceived location – a model that was later elaborated in detail by Deutsch (1981). At the time this model was proposed, physiological evidence for a separation between *what* and *where* pathways in the auditory system was sparse. However, convincing physiological evidence for such a separation has recently been obtained; for example, by Rauschecker and Tian (2000), and, more specifically, by Lamminmaki and Hari (2000) and Lamminmaki, Mandel, Parkkonen and Hari (2012) for the octave illusion. Further, in order to explain the handedness correlates with perception of the illusion, Deutsch (1981) proposed that when the pattern is presented, neurons conveying pitch information in the dominant hemisphere exert a cumulative inhibitory effect on corresponding neurons in the nondominant hemisphere; this further hypothesis awaits physiological investigation.

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The octave illusion and handedness: A replication of Deutsch's 1974 study

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Abstract

The octave illusion was first described by Diana Deutsch in 1974; in this phenomenon, a dichotic sequence of oscillating 400 and 800 Hz sinusoidal tones evokes different illusory percepts. At the same time, the obtained percepts were found to be dependent on the subjects' handedness. This study investigates the influence of the handedness classification method on the correlation between reported percept and handedness in the octave illusion. After presenting the stimulus, we asked a total of 174 subjects to report their percepts and complete a handedness inventory as well as a speed tapping task. According to the right shift theory of Annett (1972, 2002) and a related study by Kopiez, Galley, and Lehmann (2010), we hypothesized that the use of performance measurement to classify handedness may clarify ambiguous correlations of subjects' handedness with some obtained illusionary percepts. The results support the general findings of Deutsch but show that stronger effects can be found if hand performance differences are used for handedness classification. A better separation between the handedness groups could be observed, especially for the complex perception patterns.

Keywords

auditory illusion, dichotic, handedness classification, octave illusion, pitch

Introduction

The octave illusion

The octave illusion is an auditory phenomenon that was first described by Diana Deutsch in 1974 (Deutsch, 1974a, p. 357; 1974b). In the original experiment, 86 subjects were presented with dichotic, 20-s sequences of 250-ms sinusoidal tones alternating in frequency between

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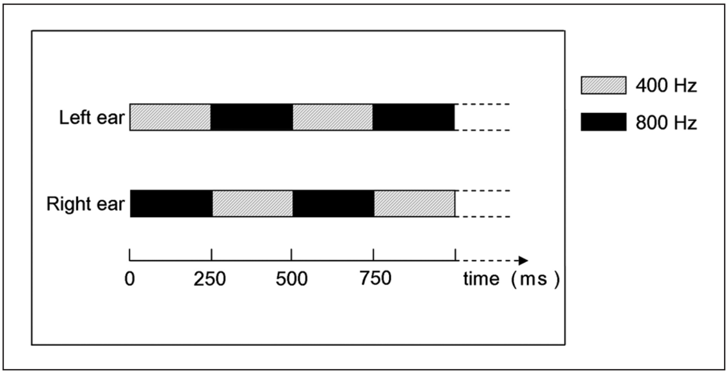

Figure 1. Stimulus pattern used in the original study by Diana Deutsch (1974b, pp. 256–257). A dichotic sequence of alternating sinusoidal tones was presented to the subjects. While one ear received a 400 Hz tone, the other ear received an 800 Hz tone, and vice versa. The two dichotic patterns are alternating at 250 ms, i.e., the entire 20 sec-stimulus sequence consists of 80 alternating subpatterns. The tones were played to the subjects at a level of 75 dB SPL, there were no gaps between the tones, and phase continuity was preserved at the transitions (reconstructed according to Deutsch, 1974b, 2004a).

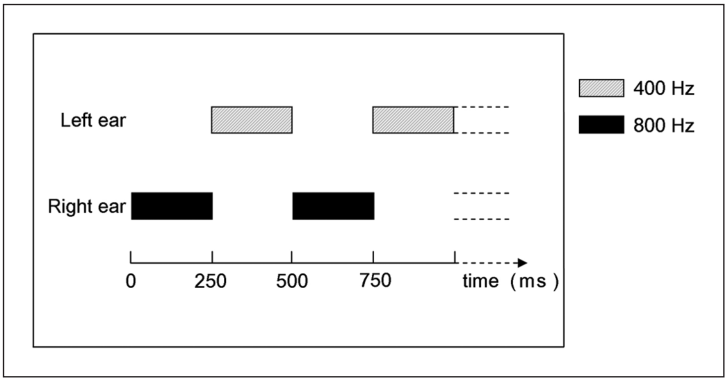

Figure 2. The most common percept of the stimulus sequence. Approximately 56 percent of the subjects hear a single tone that oscillates from ear to ear (Deutsch, 1974b, p. 307). The interval between the two tones (and between the ears) comprises one octave. Right-handed individuals tend to hear the high tone on the right ear (as displayed above), and left-handed subjects do not preferably localize the high tone on either side. In most cases, the individual localization patterns are constant (reconstructed according to Deutsch, 2004a, pp. 256–257).

400 and 800 Hz. While the right ear received 400 Hz, the left ear received 800 Hz, and vice versa. A segment of the presented stimulus pattern is shown in Figure 1.

When asked to describe what he or she heard, no subject reported the correct stimulus pattern as presented. Instead, different illusory percepts were obtained; the most common percept was a single tone that oscillated from ear to ear. Simultaneously with the localization shift, the perceived pitch oscillated from one octave to another (see Figure 2). Approximately 56 percent of the subjects reported the described percept, which was called *octave* by Deutsch (Deutsch, 1974b, p. 307). The second most commonly obtained percept (called *single pitch*) consisted of a single tone that oscillated from ear to ear, with no change or only a slight change in pitch. The perception of approximately 19% of the subjects fell into that category. The third category, called *complex*, included all other perception patterns that do not fall into the *octave* or *single pitch* categories (approximately 25% of the subjects). The same results were obtained for almost all subjects in all categories if the position of the earphones was reversed.

Handedness

Another important aspect of the original study (Deutsch, 1974b) as well as several later studies (e.g., Deutsch, 1983a, 1983b) was the perception of the octave illusion as a function of handedness. Deutsch (1974b) found that most right-handed subjects localized the high tone (800 Hz) of the octave percept on the right ear; left-handed subjects did not preferentially localize the 400 or 800 Hz tone on either ear. More right-handers (25%) than left-handers (9%) heard the *single pitch* percept, whereas more left-handed (39%) than right-handed subjects (17%) heard a pattern that fell into the *complex* category. The right- and left-handed subjects differed significantly at the specified $p < .05$ level in the relative distribution of their percepts ($\chi^2 = 6.8$, $df = 2$, $p < .05$; Deutsch, 1974b, p. 307). Deutsch proposed a *two-channel model* (or *suppression model*) to explain the observed phenomenon (Deutsch, 1975, 1978, 1980a, 1980b, 1981, 1988; Deutsch & Roll, 1976). She argued that the illusory percepts result from a dissociation between two channels, the *what* and *where* pathways in the auditory system (Deutsch, 2004a, p. 357). The *suppression model* assumes that the subjects perceive the frequencies arriving at one ear and suppress the frequencies at the other ear. The localization of the percept depends on the ear that receives the higher frequency signal (Deutsch, 1975, 1981, 1983a). The obtained correlates of the percepts with handedness can be better explained, if this phenomenon is described in a neurological setting. Within this context the pathways conveying information from different regions of auditory space are in mutual inhibitory interaction, and the strongest influence is exerted by the pathways that convey information from the dominant cerebral hemisphere (Deutsch, 1981, pp. 106–107). Considering several other studies that reported lateralization by frequency effects (Békésy, 1963; Efron & Yund, 1974; Scharf, 1974), Deutsch conducted further experiments (Deutsch, 1980a, 1980b, 1981) to investigate the effect of ear dominance, as a better understanding of the underlying mechanisms may contribute to the identification of the physiological bases of the described correlations.

Since the original study in 1974, many different aspects of the octave illusion have been explored, including the influences of tone duration (Brancucci, Padulo, & Tommasi, 2009; Zwicker, 1984), intensity (Deutsch, 1978; Sonnadara & Trainor, 2005), timbre (Brännström & Nilsson, 2011; McClurkin & Hall, 1981), musical training (Brennan & Stevens, 2002; Craig, 1979); the stability of the reported percepts (Brancucci, Lugli, Santucci, & Tommasi, 2011); selective attention (Chambers, Mattingley, & Moss, 2005); neurophysiological correlates (Lamminmäki & Hari, 2000; Lamminmäki, Mandel, Parkkonen, & Hari, 2012; Rauschschecker & Tian, 2000; Ross & Näätänen, 1996); and even its use as a promising diagnostic tool for the assessment of language lateralization (Deutsch, 2013; Ferrier, Huiskamp, Alpherts, Henthorn, & Deutsch, 2013). There has also been a vivid discussion about the fundamental perceptual mechanisms of the octave illusion, especially the validity of the *suppression model* (Chambers, Mattingley, & Moss, 2002, 2004a, 2004b; Deutsch, 1975, 2004b).

In most of the studies, handedness was considered to be an important parameter in the experimental design, and almost all studies found a correlation between handedness and the perception pattern of the subjects. A few studies did not find any correlation (Deutsch, 2004a; Herron, 1980; Zwicker, 1984), but these studies had a small sample size; however a large sample size would be required to obtain statistically significant handedness correlates. Regardless of whether handedness correlates were found, or whether the results were in accordance with the original findings of Deutsch, the procedure to measure handedness in the different studies can be divided into three categories. Either (a) the procedure was not explicitly described (e.g., Chambers et al., 2002; McClurkin & Hall, 1981), (b) the subjects were asked to (self-)report their handedness verbally (e.g., Brennan & Stevens, 2002; Chambers et al., 2002; Zwicker, 1984) or (c) a hand-preference inventory was used. Most studies (e.g., Brancucci et al., 2009; Brännström & Nilsson, 2011; Lamminmäki et al., 2012; Sonnadara & Trainor, 2005) referred to the Edinburgh inventory of Oldfield (1971), while Deutsch (e.g., 1983a, 2004a) mainly used the inventory of Varney and Benton (1975).

Except for that of Deutsch (1983b), none of the studies mentioned above described the method applied to measure handedness in detail. In most cases, the categorization of handedness seemed to be less important than most other methodological parameters. However, in the proposed hypotheses of many studies, handedness is an important parameter. This observation raises the question of whether differences in measuring handedness may be partially responsible for some of the ambiguous results, such as the different correlations between handedness and perceived patterns from those reported by Deutsch (1974b). Several studies (Bishop, Ross, Daniels, & Bright, 1996; Kopiez, Galley, & Lehmann, 2010) addressed the problem of handedness classification using inventories similar to those of Varney and Benton (1975) or the Edinburgh inventory (Oldfield, 1971).

In most of the discussed studies, handedness was a dichotomous variable (right-handed vs. left-handed). In fact, only Deutsch (1983b) differentiated left-, right- and mixed-handers, and an inventory (Varney & Benton, 1975) was still used as measurement method. Annett (1972, 2002) argued that handedness is not a dichotomous but a continuous variable that should be measured by the performance differences between both hands (Annett, 2002, p. 48), such as by means of a pegboard task. According to Annett, the variable handedness has a genetic origin in either maternal or paternal genes. Within the *right shift theory*, the (genetic) *right-loading* is called *right shift factor*. Homozygous and heterozygous people with the right shift factor show right hand superiority and may be classified as such using handedness inventories; however, individuals of the homozygous type with a missing right shift factor are more difficult to classify using handedness inventories, because atypical right-handed individuals cannot be separated from genetic ("true") right-handed individuals (Kopiez et al., 2010, p. 386). As there has been no genetic verification of handedness to date, the only method that can be used to avoid the misclassification of atypical right-handers is hand performance measurement. In this context, lateralization coefficients ($LC = 100 * (L-R)/(L+R)$) of different performance parameters (e.g., tapping speed, regularity, fatigue) are used to quantify hand performance differences. In several studies, it has been shown that the threshold between right- and non-right-handed subjects is not at the zero point but to the right (positive) of the LC distribution (Bryden, Roy, & Spence, 2007; Kopiez et al., 2010). Therefore, it is very important to determine the exact position of the threshold between right- and non-right-handed subjects. In a recent study, a binary logistic regression was used to determine an objective criterion for handedness classification (Kopiez et al., 2010). For tapping speed, an LC of 1.25 was obtained for musicians, and an LC of 1.89 was obtained for non-musicians (Kopiez et al., 2010, p. 398). More details about the statistical classification procedure and research based on that procedure can be found in Kopiez et al. (2010, 2012).

The objective of this study is to explore the relevance of the method used to measure handedness for the classification and distribution of the percepts that were found in the original study of Deutsch (1974b). Because the method that Deutsch used to measure handedness is described in more detail in later studies (Deutsch, 1983b, 2004a), these studies were also considered in the replication, but only in terms of the method and results of handedness classification and the correlation of handedness and percepts. It is hypothesized that the use of performance measurements to classify handedness may clarify ambiguous correlations of handedness with the obtained illusionary percepts. This clarification is expected to occur because atypical right-handers can be separated from right-handers, and because subjects who were excluded (Varney & Benton, 1975) or categorized as mixed-handers (Deutsch, 1983b) due to ambiguous inventory classifications can be distinctly assigned to a handedness group.

Method

Participants

A total of N = 174 music students and musicians at two universities in Vienna, Austria and Cologne, Germany, who were naive to the octave illusion, participated in our study (M = 29.1 years, SD = 7.3, 85 female, 89 male). All subjects had a minimum of six years of formal musical training (M = 11.2 years, SD = 4.2), most commonly in string instruments (30.5%), followed by piano (29.9%), guitar (8.0%), drums (7.5), vocals (6.9), flute (5.2%), and 12 more instruments with a ratio of less than 5%.

Apparatus and stimuli

The octave illusion stimuli consisted of a dichotic sequence of alternating 400 and 800 Hz sinusoidal tones; when one ear received the low tone, the other received the high tone, and vice versa. The tones were 250 ms in duration with no gaps between them (Figure 1). All stimuli were generated using MatLab on a 64-bit x86 PC (Core i7). A 16-bit PCM encoding at a 48 kHz sampling rate per channel was used. As in the original study, there were no amplitude drops at the frequency transitions, and phase continuity was preserved. All stimuli were presented to the subjects in an anechoic room at 70 dB SPL using high-quality earphones (AKG K-550). The earphones were calibrated to 70 dB SPL on a silicon calibration surface with embedded microphone (Microtech Gefell MK301E; 94 dB SPL; 3.4mV/Pa) and HOLMImpulse 1.4.2.0 software using MLS signals at one-third-octave band centre frequencies from 20 Hz to 20 kHz. A morse key (9083 by MediTech) with a trigger point of 300 g was used to measure performance differences between hands. The tap intervals were recorded using the software TAPPING (Tapping, 2008) on a 32-bit x86 PC (Atom).

Procedure

Subjects were tested individually in four different sessions on four different days. In a previous study (Oehler, Reuter, Schandara, & Kecht, 2011), several different methods of reporting the obtained percepts were tested (notation, audio-templates, forced-choice, etc.). No significant differences were found. As all subjects in this study had at least six years of formal musical training, the notation of the perceived pattern would have been an option. However we decided to use the same procedure as Deutsch (1974b) who used a forced-choice paradigm (described in Deutsch, 1983b). Therefore, all subjects were presented with a 20-second segment of the illusion and were asked to report which description best fit their percept in a forced-choice paradigm. The possible options were as follows:

(A) A high tone on the right alternating with a low tone on the left.
(B) A high tone on the left alternating with a low tone on the right.
(C) A tone switching from ear to ear with no change in pitch.
(D) None of the above (explain).

The order of options A and B and the positioning of the earphones were counterbalanced. The subjects waited until the end of the 20-second segment before choosing one option. The 20-second segment was presented only once. After that, all subjects completed the handedness inventory of Varney and Benton (1975) and a speed tapping task (index and middle finger together with a fixed wrist position) to measure the performance differences between hands. Subjects tapped for 30 seconds with each hand, and the starting hand was allocated randomly. After a recovery phase of 15 minutes, a second trial with the opposite hand as start hand was conducted. As in the study of Kopiez et al. (2010), the subjects were instructed to tap as fast as possible and to release the morse key after each tap.

Classification of handedness

According to the 10-item handedness inventory of Varney and Benton (1975) and the classification scheme of Deutsch (1983b), subjects were divided into three handedness groups. If at least 8 of 10 questions on the questionnaire were answered “right” (e.g., “with which hand do you write?”), the subjects were categorized as right-handed. If at least 8 of 10 questions were answered “left”, the subjects were categorized as left-handed. All other subjects were categorized as mixed-handed. This classification procedure of preference handedness is slightly different than the one proposed in the original article of Varney and Benton (1975), in which at least 3 of 10 questions had to be answered “left”, in order for the subject to be categorized as left-handed. Deutsch (1983b) also used the modified version, in which at least 8 of 10 questions had to be answered “right” to be categorized as right-handed and 8 of 10 questions had to be answered “left” to be categorized as left-handed. The remaining subjects were categorized as mixed-handed.

While the theoretical foundation of the used handedness classification method is Annett’s right shift theory (Annett, 1972, 2002), the measurement procedure itself is based on the findings of Kopiez and colleagues (Kopiez, 2008; Kopiez & Galley, 2010; Kopiez et al., 2010). The difference in tapping speed between hands was measured, i.e., the difference of medians of all inter-tap intervals for both hands. Regularity of tapping and fatigue were also measured, but tapping speed was the most reliable variable for the calculation of an LC to designate handedness (Kopiez et al., 2010; Peters & Durding, 1978). Regularity and fatigue were only used as control variables. Because all subjects were music students or musicians with formal musical training of at least six years, according to Kopiez et al. (2010) the LC threshold for tapping speed was set to 1.25. Subjects with an LC ≤ 1.25 were classified as designated non-right-handers (dNRH), subjects with an LC > 1.25 as designated right-handers (dRH).

Results

The distribution of handedness was measured using the handedness inventory of Varney and Benton (1975), and the corresponding percepts are displayed in Table 1. The upper part (a) shows the results of Deutsch (1983b), and the lower part (b) shows the results of this study. The percentage refers to the respective category of preference handedness. The ratio of right-, mixed- and left-handed subjects is approximately the same (displayed in column *All*). However, in our study, the proportion of subjects reporting the *octave* percept is slightly lower (83.3%) than in Deutsch’s (1983b) study (89.6%), and the proportion of subjects reporting the *complex* percept is slightly higher (8% versus 4%). Overall, the distribution pattern of the obtained

Table 1. Percepts as a function of preference handedness, as measured by inventory in (a) the study of Deutsch (1983b) and (b) the present study.

(a)	Octave		Single		Complex		All
	n	%	*n*	%	*n*	%	%
Right-handed	140	90.3	13	8.4	2	1.3	62.2
Mixed-handed	52	89.7	2	3.4	4	6.9	23.3
Left-handed	31	86.1	1	2.8	4	11.1	14.5
%		89.6		6.4		4.0	
(b)							
Right-handed	97	84.3	11	9.6	7	6.1	66.1
Mixed-handed	29	85.3	3	8.8	2	5.9	19.5
Left-handed	19	76.0	1	4.0	5	20.0	14.4
%		83.3		8.6		8.0	

percepts as a function of preference handedness corresponds to the general findings of Deutsch (1974b, 1983b). Therefore the *octave* category was by far the most common percept regardless of preference handedness, and the *complex* percept could be found more frequently in left-handed subjects.

In the first study of the octave illusion, Deutsch (1974b) only distinguished between right-handed and left-handed subjects. It is not clear whether mixed-handed participants were excluded according to the method of Varney and Benton (1975), or whether they were aggregated with either the left- or the right-handed subjects. For this reason, the three different possibilities are compared with the results of Deutsch in the next section.

Table 2 shows that the distribution pattern of the obtained percepts as a function of preference handedness in (a) Deutsch's (1974b) study resembles the versions (b), mixed-handers and right-handers aggregated, (c) mixed-handers and left-handers aggregated and (d) mixed-handers excluded. Again *octave* was the most common percept, and left-handed subjects perceived a *complex* pattern more frequently than did right-handed subjects. Deutsch (1974b) found that the two groups of right- and left-handed subjects differed significantly at the $p < .05$ level in the relative distribution of their percepts ($\chi^2 = 6.8$, $df = 2$, $p < .05$, $w = 0.28$). When aggregating (b) mixed-handed and right-handed subjects, the groups of right- and left-handed subjects also differed significantly at the $p < .05$ level ($\chi^2 = 6.1$, $df = 2$, $p = .047$, $w = 0.19$). The results are less distinct in (c) aggregated mixed-handed and left-handed subjects ($\chi^2 = 2.0$, $df = 2$, $p = .366$, $w = 0.1$) and (d) in the group in which mixed-handed subjects were excluded ($\chi^2 = 5.6$, $df = 2$, $p = .062$, $w = 0.2$).

The results of the speed tapping task are shown in Table 3. When the threshold between right- and non-right-handed subjects for the speed parameter was set to LC = 1.25, the proportion of designated right-handers (dRH) and designated non-right-handers (dNRH) was 65.5% to 35.5%. All left-handers as classified by inventory could be found in the group of dNRH; mixed-handers were rather equally distributed in the groups of dRH and dNRH; right-handers could largely be found in the group of dRH, but also in the group of dNRH (atypical right-handers according to Kopiez et al. 2010, pp. 386–387). The difference between the group dRH and dNRH was statistically highly significant at the $p < .001$ level ($\chi^2 = 33.4$, $df = 2$, $p < .001$, $w = 0.44$). The effect size Cohen's *w* was higher than in the evaluation using the inventory data and even higher than the effect size reported in Deutsch's (1974b) study. The most obvious

Table 2. Percepts as a function of preference handedness measured by inventory in (a) the study of Deutsch (1974b) and the present study with (b) aggregated mixed-handed and right-handed participants, (c) aggregated mixed-handed and left-handed participants and (d) mixed-handed participants excluded.

(a)	Octave		Single		Complex		All
	n	%	*n*	%	*n*	%	%
Right-handed	31	58.5	13	24.5	9	17.0	61.6
Left-handed	17	51.5	3	9.1	13	39.4	38.4
%		55.8		18.6		25.6	
(b)							
Right-handed	126	84.6	14	9.4	9	6.0	85.6
Left-handed	19	76.0	1	4.0	5	20.0	14.4
%		83.3		8.6		8.1	
(c)							
Right-handed	97	84.3	11	9.6	7	6.1	66.1
Left-handed	48	81.4	4	6.8	7	11.9	33.9
%		83.3		8.6		8.1	
(d)							
Right-handed	97	84.3	11	9.6	7	6.1	82.1
Left-handed	19	76.0	1	4.0	5	20.0	17.9
%		82.9		8.6		8.6	

Table 3. Distribution of percepts for the different performance handedness groups as measured by a speed tapping task (dRH = designated right-handers, dNRH = designated non-right-handers).

	Octave		Single		Complex		All
	n	%	*n*	%	*n*	%	%
dRH	107	93.9	7	6.1	0	0.0	65.5
dNRH	38	63.3	8	13.3	14	23.3	35.5
%		83.3		8.6		8.1	

difference was the considerable proportion of dRH who reported the *octave* percept and the clear distinction between dRH and dNRH in reporting *complex* percepts. In that category, only dNRH and no dRH reported *complex* percepts, as illustrated in Figure 3.

The proportion of dNRH (35.5%) in this study was relatively high compared with the results of Kopiez et al. (2010) who found a similar high proportion of dNRH only for string players (35.6%), whereas the total incidence of dNRH was 30.8% (Kopiez et al., 2010, p. 399). Even if string players were the largest group in the replication study (30.5%), this cannot completely explain the observed difference. A possible reason might be the specific distribution of instruments in this study, as the study of Kopiez et al. (2010) only concentrated on string players and pianists.

A further important finding of Deutsch (1974b) was that right-handed subjects who reported the *octave* percept predominantly heard the high tone in the right ear. Left-handed subjects did not show a distinct preference pattern. While these results could be replicated using

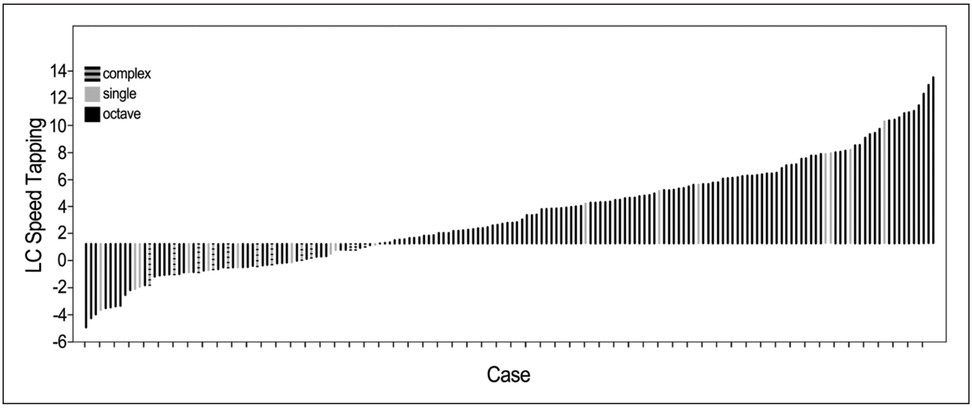

Figure 3. Continuous distribution of the lateralization coefficient (LC) in the sample of 174 subjects (threshold for the classification of non-right-handers: LC ≤ 1.25, see Kopiez et al., 2010). The percept of each subject (*complex, single* or *octave)* is illustrated by the three different types of bars.

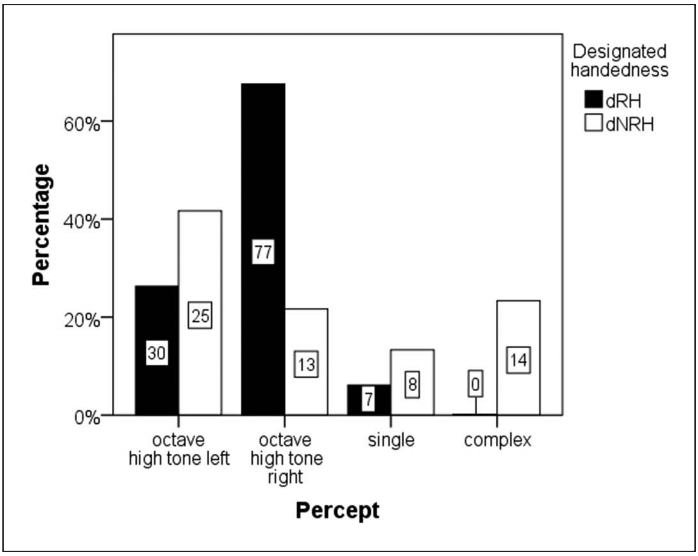

Figure 4. Distribution of percepts as a function of designated handedness as measured by hand performance differences and a classification threshold for non-right-handers of LC ≤ 1.25 (see Kopiez et al., 2010). Each value within the bars describes the number of subjects in that category (dRH = designated right-handers, dNRH = designated non-right-handers).

the preference handedness classification method, some differences were observed when using speed tapping as a classification method. As seen in Figure 4, even if the results are not significant at the $p < .05$ level, considerably more dNRH perceive the high tone on the left ear ($\chi^2 = 3.79$, $df = 1$, $p = .052$, $w = 0.32$). For the dRH, the results are comparable to Deutsch's results (1974b, 1983b): significantly more dRH perceive the 800 Hz-tone on the right ear at the $p < .001$ level ($\chi^2 = 20.65$, $df = 1$, $p < .001$, $w = 0.44$).

Discussion

The basis for our replication was the first description of the octave illusion by Deutsch (1974b). Furthermore, we focused on another key study on the octave illusion in relation to handedness and familial handedness background (Deutsch, 1983b). The second study was used because it contained the most methodical information about the measurement of handedness and data about the obtained percepts as a function of handedness. Neither study gives specific information about the distribution of musically trained (min. three years, Deutsch, 1983b, p. 291) and untrained subjects in the sample. But we did not focus on that point since Deutsch did not find any effects of musical training (Deutsch, 1983b, p. 292), and we could not find any fundamental differences concerning musical training and perception patterns in other studies (Brennan & Stevens, 2002; Craig, 1979).

In general, our results are in accordance with the findings of Deutsch (1974b, 1983b), especially in the part of our study in which we used the same handedness inventory and classification as Deutsch (1983b). However, several problems arise, when handedness is exclusively classified by a handedness inventory. In some cases, it is difficult to decide what to do with ambiguous classification results, as with the *mixed-handed participants* in the Deutsch study (1983b). While Deutsch used a criterion to distinguish three preference handedness categories based on Varney and Benton (1975) (eight or more “right” answers = right-handed, eight or more “left” answers = left-handed, the remaining subjects = mixed-handed), this procedure may differ from inventory to inventory. On the other hand, the fundamental problem of all inventory-based handedness classifications is that atypical right-handers cannot be separated from right-handers (Kopiez et al., 2010, pp. 386–387). In our current study we either excluded mixed-handers or aggregated mixed-handers with right-handers or mixed-handers with left-handers. Even if only the aggregation of mixed-handers and right-handers produced a significant effect, a similar perception pattern could be found for all versions. In other words, despite the ambiguous classification, the fundamental perception patterns of Deutsch (1974b) are evident. But the different aggregations also show that details about the distribution of percepts are lost, especially concerning the *complex* percept.

However, the proposed procedure and the statistical criterion for performance handedness classification of Kopiez et al. (2010) has been shown to be of great value in improving classification results. Speed tapping with a classification threshold of LC = 1.25 was used to differentiate between designated right-handers and designated non-right-handers. An LC of 1.25 was given preference over an LC of 1.89, as all participants had had formal musical training of at least six years, and thus it could be assumed that in terms of musical expertise the present sample could be compared with the group of musical experts in the study of Kopiez et al. (2010, p. 398).

The most important result in this context was the significantly different distribution of dRH and dNRH for the percepts *octave* and *complex*. First of all, a considerably larger proportion of dRH reported the *octave* percept and, as expected, most of them heard the high tone in the right ear. The dNRH had a strong tendency to perceive the high tone in the left ear. The small number of subjects in that condition ($n = 38$) may account for the non-significant result ($p = .052$, $w = 0.32$). Another remarkable result was the fact that no dRH, but more than 23% of the dNRH, reported the *complex* percept. At the same time, fewer dNRH reported the *octave* percept. In this case, preference handedness classification by means of the inventory apparently could not separate atypical right-handers from “true” right-handers. In other words, “hand performance measurement and preference inventory tell different stories” (Kopiez et al., 2010, p. 386).

These results are not in conflict with the findings of Deutsch (1974b), as the fundamental idea is evident in both studies: Right-handers tend to follow the information presented to their right, whereas left-handers (or dNRH) do not show this tendency and are less consistent in terms of which region of auditory space they follow because of greater cerebral equipotentiality (Deutsch, 1981, p. 107). Rather, the results of this study support many previously described perception patterns of the octave illusion. The results show that stronger effects can be found if performance measurement is used for handedness classification. Especially in the case of *complex* perception patterns, a better separation between the handedness groups can be observed.

We had not primarily intended to directly compare performance handedness and preference handedness, as there are several recent comprehensive studies in that field (Kopiez, 2008; Kopiez & Galley, 2010; Kopiez et al., 2010), but to clarify ambiguous correlations of handedness with the obtained illusionary percepts by means of performance measurements. A separation of atypical right-handers from right-handers may contribute to a better understanding of the fundamental perceptual mechanisms of the octave illusion. Even if there is some recent physiological evidence for the *suppression model* (Lamminmäki & Hari, 2000; Lamminmäki et al., 2012), it has not yet been completely understood how the two decision mechanisms of pitch perception in accordance with a dominant ear and lateralization by frequency work. The weaker and less consistent patterns of inhibition between the two pathways in the group of left-handers (Deutsch, 1981, p. 107) is reflected by the frequently observed *complex* percept in that group. The reliable separation of dNRH and dRH through performance measurement may help to structure the different variants of the *complex* percept in future research. A starting point could be the distribution of the individual LCs and percepts in Figure 3. It is remarkable that all LCs of subjects who reported the complex percept are relatively close to the LC threshold of 1.25 and there are no subjects with a LC below -2.01. The relevance of these findings in the context of the fundamental perceptual mechanisms of the octave illusion and the role of cerebral dominance should be the focus of future research. However, because the proportion of subjects that obtain complex percepts is relatively small, a larger sample size would be required.

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