MULTISENSORY PRODUCT DEVELOPMENT

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Abstract

The sensory design of products plays an important role in the customer's overall assessment of quality. While sensory design comprises of visual, acoustic and haptic aspects, the combination of these aspects and hence the multisensory product design becomes increasingly important. However, for a successful realization of a multisensory design, the human cognition and multisensory perception has to be considered. In this paper, the phenomenon of multisensory enhancement as well as dissonance owing to sensory mismatch was examined by means of an empirical study with 98 test persons. The use case of aged products was investigated. It was hypothesized that (1) products are perceived older if aged equally regarding all primary senses and (2) the perception of harmony suffers from sensorially dissimilar aged products. Using a Maximum-Likelihood-Estimation as a reference value for the multisensory product age, the first hypothesis could be confirmed through a statistical analysis. However, the second hypothesis had to be rejected for this empirical setup, i.e. sensorially mismatching products were not perceived less harmoniously.

Keywords: Multisensory product experience, Case study, Emotional design, Perceived quality

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1 INTRODUCTION

The user, his preferences and perception are of core interest within product development. Preferences and perceptions are influenced by a product's technical functionality, it's aesthetics, reliability and sensory design. While sensory design has in the past mostly focussed on visual aspects, haptic, acoustic or even olfactory design aspects are now equally important (Schmitt, 2014; Steiner, 2011). The "touch-feel" of a surface or the "powerful sound" of a machine have strong influence on overall perception and assessment of quality. Therefore, companies aim at developing products, which meet the customers' requirements regarding all senses.

Yet, successful sensory design requires precise design matching. Design matching refers to matching of sensory information among the primary senses. Disparity in sensory information could lead to dissonance, the perception of disharmony and in the worst case, rejection of the product (Skrandies and Reuther, 2008). For example, a surface which conveys a metallic condition but feels too warm evokes perceived inconsistencies and possibly degradation of the perceived product quality. On the opposite, a semantic match of sensory information can actually support the user's attention according to the concept of 'multisensory enhancement', originating from neural science; e.g. one can recognize a dog faster, if presented the animal visually (picture) and acoustically (barking sound) simultaneously (Senkowski *et al.*, 2008).

However, research regarding multisensory product development to date focuses mostly on the timely or locally redundant sensory information, i.e. to support the user in his perception by superposition. Whether the semantic matching significantly alters the product perception has not yet been investigated extensively in research.

In this paper, the multisensory perception of products will be examined focusing on the use case of products’ age. Since product aging underlies subjectivity to a certain degree, but does not depend heavily on preferences, it is chosen as a practical case for the above-mentioned topic. The perceived age of two exemplary products will be empirically investigated, namely a pencil case and computer mouse. To this end, these two products are artificially aged regarding visual, acoustic and haptic product features. However, in order to examine the effect of a semantic match and mismatch respectively, the cases and mice are not aged uniformly, but either with respect to visual features, or with regard to haptic and acoustic features. Within an experimental study participants are presented the manipulated products and asked for their subjective perception concerning their age and harmony. By means of statistical analyses, it is examined whether the sensory match regarding age leads to the hypothesized multisensory enhancement, and whether the sensory mismatch of products’ age leads to the hypothesized dissonance of product perception.

The paper is structured as follows. In section 2, the state of the art regarding multisensory product development with special focus on multisensory perception will be outlined. In section 3, the research methodology and experimental setup will be presented, followed by the illustration of results in section 4 as well as a summary and outlook in section 5.

2 MULTISENSORY PRODUCT DEVELOPMENT

The importance of designing products which address all of the customer's senses has been increasing throughout the last years (Haverkamp, 2009). On the one hand, the transmission of information via different senses is applied for safety measures: Warning signs in cockpits are rather sent e.g. via the acoustic sense to relieve the visual sensory system. Or, warning signs (e.g. lane assist in cars) are provided redundantly through the visual and haptic sense to ensure non-dissipative information transfer. On the other hand, the designing of sensual product properties is specifically used to create unique brand characters, known by the cue word 'sensual branding' (Steiner, 2011). Companies not only use the visual design to differentiate from their competition, but use also haptic, or even olfactory design as unique brand features (Faganel and Janes, 2015). However, in order to integrate a multisensory design into products and not just develop different sensual properties, a profound understanding of multisensory perception and eventually the matching of sensory product characteristics is necessary.

2.1 Multisensory perception

For comprehending human perception and especially the interaction between the different senses, details of multisensory processing, sensory uptake as well as the phenomenon of multisensory enhancement must be understood. The basics and current state of research from perceptual psychology, neuro- as well as cognitive science will be presented henceforth.

2.1.1 Multisensory processing

Information about the environment are always perceived multisensory (Hagendorf *et al.*, 2011). The integration of several senses as source of information about the environment improves the quality of perception (Haverkamp, 2009). Redundant or supplementary information, which are obtained by means of different sensory modalities are a necessary requirement for the action or reaction of humans. For example, a tennis player is not capable of reacting and returning fast enough based only on the visual intake of information, that is without the corresponding sound (Haverkamp, 2009).

The so called 'binding problem' considers the development of a holistic overall impression as a result of the information intake via diverse sensory channels. Processing can be regarded as the bottleneck in multisensory perception with peak processing speeds being 16bit/sec and average processing speed being 10bit/sec (Zühlke, 2012). Contrary to former theories - which regarded a cognitive processing convergence exclusively forward-oriented - research to date assumes, that the sensory systems interact with each other during the integration process, influence each other and are quickly (re-)combined for a new perception image (Senkowski *et al.*, 2008).

2.1.2 Object recognition and assembly model

Prior to the information transformation and object recognition within the cognition process, physical and chemical stimuli are taken up by the organs of perception. These stimuli, received via so called receptors, are being converted into electrical impulses and thus into a data format, in which they can be forwarded to the central nervous systems. That followed, they are being processed neuronally (Haverkamp, 2009); (Schmidt *et al.*, 2010). The uptake of distinct characteristics (bottom-up) of the environment triggers the process of object recognition and the separation of objects on a cognitive level. The term characteristic refers to the fundamental sensory data of an object, e.g. colour, shape, movement (Shimojo and Shams, 2001). By analysing relations among characteristics, and by grouping or 'binding' of characteristics, it is possible to uptake coherent information or coherent objects and distinctly classify them as such, to perceive them as a bundle information and to ascribe meanings to these coherent objects. The integration of characteristics results from principles which to date are applied as strategies for visual object recognition, e.g. the principle of proximity, of continuity, of similarity, of shared direction of motion, of closed structure, of symmetry or of sequence (Karnath and Thier, 2012). In neuro science, this assumption of bottom-up perception is supported by latest findings (Karnath and Thier, 2012), the so called assembly model offers a possible solution statement. Through the transmission of stimuli by the sensory systems to the central nervous system, neurons are being activated in the different areas of the brain. Visual information concerning complex objects are not encoded as a whole by single neurons. Rather, many neurons take part in the object identification; they each react to different characteristics as partial information of an object. According to the assembly model, those neurons, which respond to the same objects, fire their electrical impulses synchronously. Thereby, they build coherent 'nerve associations', i.e. assemblies, which correlate in their timely activities, refer to Figure 1 for illustration. (Karnath and Thier, 2012)

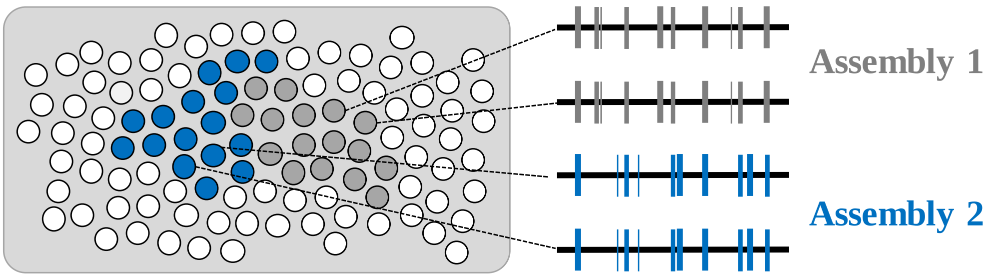

Figure 1. Coherent activity patterns of differing assemblies as codification of the neural response towards visual stimuli from diverse objects (Karnath and Thier, 2012)

The frequency band of the synchronous activities, which are sent by the nerve assemblies within the integration process, are located between 30 and 100 Hertz (Karnath and Thier, 2012). This frequency band is also called gamma band and plays an important role in the perception process. Brain activities in this band go along with an increased attentiveness, performance and a decreased risk of failure (of a person) (Haverkamp, 2009). Furthermore, the information sent by the synchronous nerve assemblies are forwarded with greater preference within the information selection process (Schmidt *et al.*, 2010). By means of EEG studies, an increased gamma band activity was detected, as stimuli were up taken in a multisensory fashion. This activity was enforced, if the multisensory stimuli were designed according to the principle of "integration through coherence" (refer to section 2.1.3). The validity of the assembly model for intersensory binding is not yet proven. Diverse findings support, however, that the above-described integration of characteristics also holds for multisensory stimuli, i.e. that the assembly model is also applied in the multisensory perception (Müller 2015, Weiser 2012) (Karnath and Thier, 2012). In the following, the concept of multisensory enhancement will be illustrated.

2.1.3 Multisensory enhancement

The term multisensory enhancement has been established in the context of research regarding multisensory integration and information processing (Senkowski *et al.*, 2008). Multisensory enhancement describes the phenomenon of an enhancing effect, which the information intake via different sensory systems has on the perception. It underlines the hypothesis of "integration through coherence" on a neuronal level and can be triggered by three difference principles: timely coherence, spatial coherence and semantic coherence. The first two principles have already been subject of research and are applied in industrial practice (Bubb *et al.*, 2015).
Thus, the principle of semantic coherence will be focus of this research. In order to investigate whether the concept of multisensory enhancement by the principle of matching semantics can be validated in the context of product perception, a use case is developed and studied empirically. In this use case, the aspect of aging of a product will be explored. The perceived age of a product connected to a decay of sensory properties of a product eventually leads (besides other influences) to product obsolescence and therefore plays an important role for the customer (Cooper, 2004).
The following research question guides this paper: Does sensory match or mismatch of information influence the perception of the age of a product and the general perception of quality and harmony of the product, respectively.
Henceforth, the current research will be illustrated, including the formulation of hypotheses and the detailed description of the experimental study.

3 EXPERIMENTAL RESEARCH OF MULTISENSORY PERCEPTION OF OBSOLESCENCE

An empirical study was conducted to investigate the perceived age and harmony of aged products. With regard to the research question and considering the fundamentals of multisensory perception, the following was hypothesised:

Hypothesis 1: Presented products are perceived older, if they are comparably aged in their visual, haptic and acoustic characteristics in comparison to the presented products which are solely aged in either their visual or haptic-acoustic characteristic.

Hypothesis 2: Presented products are perceived more harmoniously if they have matching sensory characteristics regarding age in comparison to a sensory mismatch.

Within this research, only the three senses 'visual', 'acoustic' and 'haptic' were considered, for they are the most relevant for the perception of many products (Mahlke, 2008). Henceforth, the choice of products as well as the sensory manipulation thereof (section 3.1), the operationalization of terms (section 3.2) and the setup of the empirical experiment (section 3.3) will be illustrated.

3.1 Choice and sensory manipulation of products

The two products chosen for this study were a pencil case and a computer mouse. The criteria for the product were that it had to be an object which (1) supposedly most people use or had used in daily life, (2) is usually perceived multisensory, i.e. used visually, haptically and acoustically, and (3) is relatively simple regarding the diversity of usage scenarios. The first criterion owes to the fact that participants of the study must have an idea in which way the specific products ages. Thus, a relatively new product such as a fitness tracker or a new smart phone was not suitable. The second criterion is necessary regarding the objective of this study. A product, which is mostly used e.g. visually or acoustically was not seen as appropriate for the examination of multisensory perception. The third criterion is very important concerning the feasibility of the study. The products chosen ideally had a limited number of possibilities to perceive it in a unisensory manner. For example, a product such as a laptop already has numerous buttons, a touch-pad and a shell which users can perceive haptically. A manipulation of the diverse haptic functions would render an inquiry about the perception of aging in this sense rather challenging due to the numerous influencing factors. For the purpose of this study, the products were artificially aged. That is, characteristics of the products were changed for an aged appearance. In order to respond to the research question (refer to section 2), products were not manipulated uniformly regarding age, but rather unisensory, keeping the residual sensory information in mint condition. For example, the visual appearance of a pencil case was aged artificially, but the acoustic and haptic characteristics maintained in mint condition. Furthermore, only those characteristics were manipulated, which did not directly influence another sense. That is, e.g. the surface of the pencil case was not softened intensively, for it would have caused a haptic effect as well as a visual effect simultaneously. With regard to the experimental study and the feasibility of manipulation, haptic and acoustic information were treated combined, i.e. either manipulated regarding age or maintained 'as new'. The choice of the manipulated characteristics was based on a pre-study concerning customer review from Amazon. The characteristics which - if decreasing over the time of usage - accordingly convey aging of the specific product mostly and fulfilled the above-named conditions, are listed in Table 1.

Table 1. Manipulated characteristics of products

Product / Basic sense	Visual	Haptic	Acoustic
Pencil case	Leather surface	Haptics of zipper	Sound of zipper
Computer mouse	Surface, brand logo	Haptic of mouse button	Sound of mouse button

Pencil case

For the manipulation of the visual age of the pencil case, artificial stains were applied on the leather surface, red marker was applied to the zipper (refer to Figure 2).

Figure 2. Visual manipulation of the pencil case

For the haptic-acoustic aging, the zipper was roughened and minimally bend. Through this simulation of many using operations, the zipper was (haptically) more difficult to open and close, in terms of a higher resistance. Furthermore, the sound of the zipper was alternated towards deeper sounds, which conveyed an aged pencil case in accordance with the pre-study.

Computer mouse

For the manipulation of the visual age of the computer mouse, the surface was matted, indicating intensive use. Also, dirt was applied to the gap around the mouse wheel and the brand logo was alternated simulating fading. See the two left figures in Figure X for the visually aged computer mouse. For the haptic-acoustic aging, the mouse buttons were manipulated. Therefore, the mechanical transmission element of the buttons was shortened, see marked elements in the right figure of Figure 2. Consequently, less force is necessary to operate the mouse buttons. Hence, the haptic feedback is softened, simulating worn-out springs. Furthermore, the typical "click"-sound was damped by the cutting of the transmission elements, equally indicating acoustically worn-out mouse buttons (refer to right figure in Figure 2).

Figure 2. Visual (figures on the left) and haptic-acoustic (figure on the right) manipulation of the computer mouse

In total, each four pencil cases and computer mice were manipulated, henceforth referred to as (test) objects. See Table 2 for the setup regarding matching and mismatching sensory characteristics and the corresponding codification.

Table 2. Setup of multisensory matches and mismatches

		Visual appearance	
		Mint condition	Artificially aged
Haptic-acoustic appearance	Mint condition	Match (V+ HA+)	Mismatch (V- HA+)
	Artificially aged	Mismatch (V+ HA-)	Match (V- HA-)

3.2 Operationalization of terms and questionnaire

With regard to the hypotheses and research question, the factors "perceived age" and "perceived harmony" were operationalized using a questionnaire. The perception of age was decomposed into three sets of items to ensure internal consistency. First, the test persons were asked how old they rated the object within the predefined scale: 'brand-new', 'as good as new', 'slight traces of use', 'used' and 'strong traces of use'. Second, the test persons were encouraged to evaluate the age (max. ten years) in a free text-field. Third, semantic differentials were applied; On a Likert scale from one to seven, the test persons assessed the objects regarding four pairs: new:1 - old: 7, reliable:1 - unreliable: 7, presentable:1 - not presentable: 7, pleasant: 1 - unpleasant: 7.
For the perception of harmony of objects, semantic differentials were used likewise: coherent: 1 - incoherent: 7, acceptable: 1 - unacceptable: 7, fitting: 1 - unsuitable: 7, predictable: 1 - surprising: 7. In addition, the 'overall impression' was to be stated on a scale of one (positive: 1) to seven (negative) as an indicator of harmony.

3.3 Setup of empirical experiment

The setup of the empirical experiment included the sequence of objects presented as well as the instructions and surrounding conditions of the experiments. See Table 3 for the sequence of the presented objects (compare with Table 2 for the codification). The test persons were asked in part (A) to answer some basic demographic questions, including gender, their age, profession and monthly net income. Prior to the main sensory tests (PC1-PC6/CM1-CM6), in part (B) and (D) the test persons were presented the object (pencil case or computer mouse) in mint condition as a reference. Also, in part (B) and (D), they were posed questions about their general usage behaviour regarding pencil cases and computer mice, respectively. They were asked whether they already had used the product, in case of yes, under which circumstances (predefined answers: "school", "studies", "work spare time", "other"), if they currently possessed the object and if yes, how often they use it ("frequently", "occasionally", "practically never"). The main sensory test consisted of a unisensory (C.1 and E.1) and a multisensory part (C.2 and E.2). The unisensory part of the study served for the comparison regarding the hypothesis of multisensory enhancement. Therefore, the pencil case and computer mouse with the codification V-AH- were each presented for ca. 15 seconds in such a way that the test persons were able to use solely one primary sense for perception.

Table 3. Sequence (A)-(E) of information collection and object presentation

(A) Demographic questions				
Pencil case 	(B) Basic questions: usage behaviour pencil case // presentation of pencil case in "mint condition"			
	(C) Sensory test	Perception by sense	Object presented	test number
	(C.1) Unisensory	Haptic	V- HA-	(PC1)
		Acoustic	V- HA-	(PC2)
		Visual	V- HA-	(PC3)
	(C.2) Multisensory	Visual/haptic/acoustic	V+ HA-	(PC4)
		Visual/haptic/acoustic	V- HA+	(PC5)
		Visual/haptic/acoustic	V- HA-	(PC6)
Computer mouse 	(D) Basic questions: usage behaviour computer mouse // presentation of computer mouse in "mint condition"			
	(E) Sensory test	Perception by sense	Object presented	test number
	(E.1) Unisensory	Haptic	V- HA-	(CM1)
		Acoustic	V- HA-	(CM2)
		Visual	V- HA-	(CM3)
	(E.2) Multisensory	Visual/haptic/acoustic	V+ HA-	(CM4)
		Visual/haptic/acoustic	V- HA+	(CM5)
		Visual/haptic/acoustic	V- HA-	(CM6)

For the exclusively haptic sensory test, the test persons were given earmuffs; additionally, they were requested to close their eyes. Similar measures have been taken for the acoustic and visual sensory test. That is, for example, the study leader operated the objects for the test person to perceive it merely acoustically. In the multisensory tests, the sensory perception of the test persons was not limited in any way, i.e. they were allowed to touch, hear and see the test object for about 15 seconds.
After the presentation of each object (PC1-PC6/CM1-CM6) the test persons were asked to answer seven to twelve questions regarding their perception of age and harmony respectively, as illustrated in section 3.2. Obviously, when objects were presented unisensory, the five questions about the impression concerning the harmonic perception were not posed. Henceforth, the results will be presented, followed by a summary and discussion of further research in section 5.

4 RESULTS

In total, 98 test persons participated in the experiment, 39 of whom were male and 59 were female. The participants' age ranged from 18 to 50 years and they took in average 25 minutes to finish the experiment. All participants indicated that they had already used or are still using a pencil case and computer mouse. It can thus be assumed that each test person has an association with the aged condition of said products from their experience.
To test consistency of the item construct of the questionnaire, Cronbach's Alpha was calculated. For the perception of age, it was $\alpha_A = 0.9234$, when calculated with standardized data. The computation was conducted with respect to the responses regarding the predefined scale of age (converted to an interval scale), the free text field and the semantic differential over the twelve sensory tests, thus six items. Cronbach's Alpha for the perceived harmony was computed considering the five semantic differentials of harmony (including the question about the overall impression) and amounted to $\alpha = 0.9410$, when calculated with standardized data. Considering only the first three semantic differentials and the assessment of the overall impression (coherent - incoherent, acceptable - unacceptable, fitting - unsuitable, positive - negative) rendered a Cronbach's Alpha of $\alpha_H = 0.9610$ for the perceived harmony construct: The differential 'predictable - surprising' was thus neglected for further analysis.

Analysis of perceived age

Since Cronbach's Alpha for the perceived age was sufficiently high, the focus on the statistical analysis laid on the estimated age in the free text field, further referred to as variable A_{tj} (t: test number, j: number of test person). See Figure 3 (pencil cases on the left, computer mice on the right) for the distribution of arithmetic means of perceived age by test. Grey figures represent the unisensory tests, whereas blue figures illustrate multisensory tests.

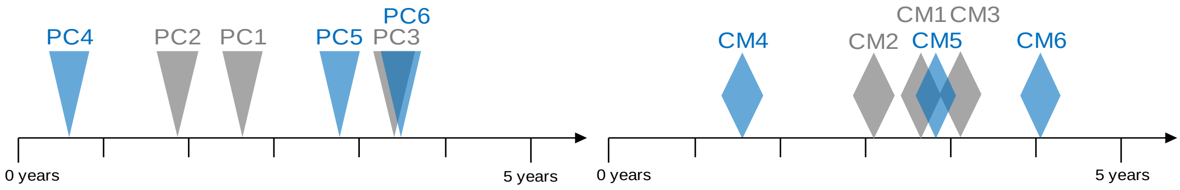

Figure 3. Arithmetic mean of perceived age by product over time

Refer further to Table 4 for the numerical data of arithmetic mean and standard deviations of the estimated age. Obviously, the haptic-acoustically and visually aged test objects in the multisensory test (PC6 and CM6) were evaluated as 'the oldest', the mean values being 4.43 years and 5.05 years, respectively.

Table 4. Arithmetic mean and standard deviation of perceived age of free text fields

Sensory test (t)	PC1	PC2	PC3	PC4	PC5	PC6	CM1	CM2	CM3	CM4	CM5	CM6
	Unisensory			Multisensory			Unisensory			Multisensory		
Arithmetic Mean $\bar{A}_t$	2.68	1.91	4.40	0.65	3.80	4.43	3.70	3.08	4.08	1.64	3.79	5.05
Standard deviation	2.84	1.73	2.78	0.76	2.34	2.80	2.85	2.46	2.17	1.82	1.80	2.16

In order to test Hypothesis 1, a reference value was developed. There are few quantitative models for the composition of multisensory perception on the basis of unisensory data. In this research the statistical model by Ernst and Bülthoff (Ernst and Bülthoff, 2004) will be applied, which is predicated on the idea of a maximum-likelihood-estimation (MLE) for the multisensory percept. Other researches support the general idea of MLE for the estimation of multisensory perception (Jazayeri and Movshon, 2006). According the Ernst and Bülthoff, the multisensory percept $\widehat{M}$ can be modelled as a sum of unisensory data M_i, see to Equation (1). The weights w_i of the senses is built based on the reciprocal of noise (Equation (2)), i.e. the variance of perception by sense (Equation (3)).

$$\widehat{M} = \sum_{i=1}^{n} w_i * M_i \,, \sum_{i=1}^{n} w_i = 1 \tag{1}$$

$$w_i = \frac{r_i}{\sum_{k=1}^{n} r_k} \tag{2}$$

$$r_i = \frac{1}{\sigma_i^2} \tag{3}$$

In their study, the authors calculate the variance as the deviation from the true value. E.g. the variance in visual perception appears when the visual features do not match the haptic, hence the visual perception is altered. Ernst and Bülthoff state that each sense's influence can be measured by its insensitivity to alteration. In the current study, the true value of the products' age is unknown. However, one could argue that the true age equals the subjective perception by sense over all tests persons, i.e. the means presented in Table 4. The variance will thus be calculated as the difference between the unisensory ages and the multisensory ages, see Equations (4) - (6) with indices for the pencil case. The variance for the computer mice are calculated accordingly.

$$\sigma_{A_{H.PC}}^2 = \sum_{j=1}^{98} (A_{PC1,j} - A_{PC4,j})^2 \tag{4}$$

$$\sigma_{A_{A.PC}}^2 = \sum_{j=1}^{98} \left(A_{PC2,j} - A_{PC4,j}\right)^2 \tag{5}$$

$$\sigma_{A_{V.PC}}^2 = \sum_{j=1}^{98} (A_{PC3,j} - A_{PC5,j})^2 \tag{6}$$

See Table 5 for the calculated weights (%) of senses by product. For an upper approximation, the higher values for each sense was considered for the calculation of the multisensory percept even though clearly the sum of weights did then not add up to 100%; w_H= 17.35%, w_A = 36.03% and w_V = 59.77%.

Table 5. MLE weights in % (based on Ernst and Bülthoff)

Product / Sense	Haptic (H)	Acoustic (A)	Visual (V)
Pencil case	16.47	36.03	47.50
Computer mouse	17.34	22.89	59.77

The estimated multisensory percept $\widehat{M}$ for haptically, acoustically and visually aged products was computed according to Equation (1) for each test person, M_i being the estimated age from the unisensory tests. The average age for pencil case summed up to $\widehat{M}_{PC6} = 3.78\,years$ (computer mouse: $\widehat{M}_{CM6}$ =4.19 years) with the standard deviation of $\sigma_{\widehat{M}_{PC6}} = 2.28\,years$ (computer mouse: $\sigma_{\widehat{M}_{CM6}} = 2.31\,years$). A one-sided Mann-Whitney U-test was conducted to test H1. Specifically, the alternative hypothesis to be proven was formulated as: H1: $\widehat{M}_{PC6} < \bar{A}_{PC6}$, likewise for computer mice. The test yielded a significant difference $\alpha = 5\%$ between the calculated multisensory age and the estimated multisensory age by test persons (Pencil case: $W = 10351{,}0$; $p = 0.0395$ / Computer mouse: $W = 10764{,}0$; $p = 0.0007$). Thus, the hypothesis, stating that the perceived age for the multisensory matching products is older than for products which have solely been aged unisensory, can be confirmed for both products. The occurring multisensory enhancement is not as apparent for the pencil cases, possibly due to the artificial aging. As can be seen from the data (compare to Table 4), the unisensory age tests turned out differently by senses for the two products: for the pencil case the haptic age was on average estimated as 2.68 years, the acoustic age 1.91 years, compared to visual age of 4.4 years. In contrast, the unisensory age for the computer mouse was 3.7 years by haptic perception, 3.08 by acoustic and 4.08 years by visual perception on average. Hence, the enhancement was stronger, when the unisensory age estimation based on the haptic and acoustic senses was already higher.

Analysis of perceived harmony

Due to a high Cronbach's alpha, the items (semantic differentials) were combined into a factor $\bar{H}_t$, i.e. the arithmetic mean of harmonic perception was calculated by test person. See Table 6 for the arithmetic means, median values by multisensory test and the corresponding standard deviations over all test persons, with lower values representing a harmonic impression and higher values representing disharmonic impression.

Table 6. Means and standard deviation of perceived harmony regarding multisensory tests

Multisensory test	PC4	PC5	PC6	CM4	CM5	CM6
Arithmetic mean $\bar{H}$	1.99	3.53	3.84	2.40	3.19	4.26
Median	1.75	3.50	3.88	2.00	3.00	4.25
Standard deviation	1.05	1.41	1.58	1.49	1.41	1.57

A Kruskal-Wallis-Test was conducted to analyse whether perception of harmony varied between the different test objects within the two object groups. For the pencil cases, the null hypothesis of equality could be rejected ($p = 0.000$; $z_{PC4} = -9.03$, $z_{PC5} = 3.60$, $z_{PC6} = 5.43$). Similar results were yielded for the computer mice ($p = 0.000$; $z_{CM4} = -6.82$, $z_{CM5} = -0.27$, $z_{CM6} = 7.09$), indicating significant differences in the harmonic perception of aged and non-aged test objects. However, in contrary to H2, the objects designed to feature a sensory mismatch (here: PC4, PC5 and CM4, CM5) were not perceived more disharmonic than the objects with a sensory match (here: PC6 and CM6). In fact, the opposite appears to be the case. Despite the rejection of the hypothesis, the data indicate some underlying principle of perception. The relations between the harmonic perception are equal for both products, i.e. $\bar{H}_{PC4} < \bar{H}_{PC5} < \bar{H}_{PC6}$ as well as $\bar{H}_{CM4} < \bar{H}_{CM5} < \bar{H}_{CM6}$. One explanation could be the set-up of the experiment and the use case of aged products. Possibly, the interrogation concerning the perceived age outweighs the judgement of harmony, refer to Figure 4.

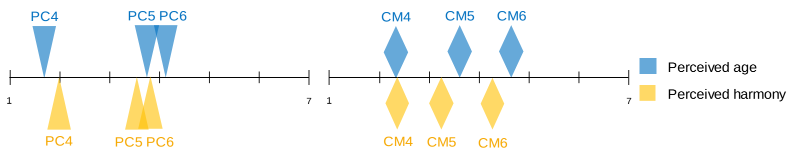

Figure 4. Comparison of resulting means of semantic differentials

Indeed, plotting the arithmetic means of the Likert Scales (semantic differentials) for both constructs reveals some similarities. A different experimental setup can be a measured to re-test and possibly confirm the second hypothesis in further research.

5 SUMMARY AND DISCUSSION

Objective of this paper was to investigate whether the multisensory match of product characteristics regarding their age has a significant influence on their perceived age through a mechanism called multisensory enhancement. Further it was examined if a sensory mismatch affected the perceived harmony of products. To this end, two products' haptic, acoustic and visual characteristics were artificially aged. A questionnaire was developed and the proximate empirical study was conducted with 98 test persons. The phenomenon of multisensory enhancement was verified by means of a statistical analysis comparing the age of products when perceived multisensory by test persons to an estimated age based on unisensory age perception. By abstracting from the use case of 'age', the importance of sensory matching of characteristics in product development is supported. The fitting of sensory information can be useful when designing brand attributes such as sportiness or playfulness.

The assumption of a stronger disharmonic perception of products with unequal sensory characteristics were however not supported by the study results. For latter findings, further research should be conducted, including varying the study setup, using different products or altering additional properties than 'age'.

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