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INTERVENTION STUDY

Does Touching Real Objects Affect Learning?

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Abstract
Based on theories of multimedia learning, the present study investigated whether the haptic sense serves as an additional channel to enhance the learning experience and learning outcomes. We therefore set up an experimental exhibition with two showrooms. In the first showroom, the sensory access of the participants to the exhibition objects was systematically varied in a 2 × 2 design with the between-subjects factors vision and haptics. While one group of participants could touch and see the objects, others could either only see or only touch them. The fourth group of participants found a showroom without objects. To address the auditory access, all participants were provided with information about each object via an audio guide. In the second showroom, further information was presented using posters. This showroom was the same for every participant. We aimed to investigate whether the haptic experience in the first showroom served as a motivator to engage further with the topic. The participants filled out questionnaires before visiting the first showroom, after visiting the first showroom, and after visiting the second showroom. To investigate the differences between the experimental groups on different outcomes, a memory test, a knowledge test, and various motivational-affective scales were used. The long-term effects of the information presentation were measured after 3 weeks. We found an advantage for recalling the objects and a heightened negative affect due to the haptic experience. Implications and further directions for this research will be discussed.

Keywords Haptics · Multimedia learning · Situational interest · Memory · Real tangible objects

The haptic sense is an indispensable part of our everyday life. It plays an important role when we try to find the light switch at night, when we want to assess the ripeness of an avocado, or for social interaction with our fellow human beings, such as hugging and shaking hands. Therefore, the haptic sense is crucial for interacting with the environment and with each other, forming an integral part of our multimodal system (Minogue and Jones 2006; Smith and

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Gasser 2005). Although touch plays an important role in exploring and getting to know the world around us, it has been far less researched than visual and auditory senses (Gallace and Spence 2009), and it is often neglected in learning theories, especially in multimedia learning theories. To help to fill this research gap, the present study uses a multi-criteria approach to investigate the influence of haptic exploration of real, three-dimensional, tangible objects on learning experience and learning outcomes. We are interested in the question of whether the haptic sense—together with the visual and auditory senses—can serve as an additional channel for comprehending the learning material and thus support the learning process.

Bodily Experiences as Resources for Learning

In recent years, the importance of bodily experiences for mental processes has been established both theoretically and empirically, demonstrating that cognition is closely intertwined with the sensorimotor characteristics of human bodies (Barsalou 2010; Glenberg et al. 2013; Wilson 2002). In this view, cognition is instantly coupled with the present environment through bodily activities. If possible, external resources are exploited in order to situate cognitive processes, thereby simplifying mental routines, minimizing errors, and decreasing cognitive load (embedded cognition; Pouw et al. 2014). Also, information from the environment is not simply passively registered. Instead, the human body constitutes a fine-tuned perceptual system, which explores its surrounding by an intricate interplay of motor behavior (including movements of the eyes, the head, the limbs, or the whole body) and sensory receptors (including eyes, ears, nose, tongue, and skin; Gibson 1966). While seeing, hearing, and smelling gather information from a distance, touching (and tasting) brings the body in direct contact with other beings, artifacts, or materials. With few exceptions, like dark or noisy conditions, both vision, hearing, and touch work in concert (Hollins 2010). Accordingly, the development of eye movements in service of goal-directed vision during early childhood is paralleled by a corresponding development of motor behavior (touching, grasping) in service of manual scrutinization of objects, eventually resulting in a set of haptic exploratory routines (Lederman and Klatzky 1987, 2009).

Embodied cognition does not only support successful behavior in a given situation but extends to “offline” cognition as well. According to the perceptual symbol system account, sensorimotor input will be permanently stored in long-term memory and can be re-instantiated even when the mental apparatus is decoupled from the original situation in which the embodied experience took place (Barsalou 2010; Wilson 2002). Thus, sensorimotor experiences constitute fundamental elements of mental representations, which allow for successfully coping with future situations (Glenberg 1997).

Within this framework of embodiment, haptic exploration may contribute to offline cognition and learning in several ways. Firstly, it adds an additional layer of sensorimotor input, contributing to an enriched mental representation that can be easily accessed and re-instantiated (Hutmacher and Kuhbandner 2018; Lacey and Sathian 2014). Secondly, re-activation of stored efferent activities may be fed into forward models which allow the cognitive system to emulate actions in an offline manner (Glenberg et al. 2013; Grush 2004). In this way, haptic-based motor imagery complements visual imagery, resulting in mental simulations of possible uses of objects, tools, or materials, as evidenced by increased frequencies of gestures during verbal descriptions of object manipulations (Hostetter and Alibali 2008; Kamermans et al. 2019).

Thirdly, according to Paas and Sweller (2012), object manipulation is a privileged type of learning that allows for acquiring biologically primary knowledge; that is, humans are evolutionarily disposed to acquire knowledge through manual exploration of objects in an unconscious, effortless, rapid, and intrinsically motivated manner, for which the constraints of working memory with limited capacity do not apply. Accordingly, due to its highly motivating character and its ease of acquiring knowledge and skills, this “natural” mode of learning plays a great role outside of formal learning contexts from early childhood on (Geary 2008). But, it may also be successfully utilized to support acquiring biologically secondary knowledge in educational settings (Paas and Sweller 2012; Pouw et al. 2014), with examples ranging from finger tracing to hands-on experimentation to re-enactments (e.g., Stull et al. 2018; Tang et al. 2019; Zacharia 2015).

Facets of Haptic Exploration

While passive touch means being touched by a stimulus or a person, for example, by an object being pressed against the skin, active touch implies that someone chooses to explore and manipulate an object manually to obtain information about the properties of the object (Minogue and Jones 2006). Such haptic exploration includes several different sensations that may contribute to the learning experience. Firstly, it is typically based on hand movements. Similar to gestures, such coordinated muscular movements can be considered examples of embodied cognition, resulting in memory traces that make an additional contribution to the mental representation of the phenomenon or concept explored (Pouw et al. 2014). Accordingly, research on finger tracing has demonstrated that learners benefit from tracing a certain shape (for example, temperature curves or the water cycle) with the index finger (Agostinho et al. 2015; Ginns et al. 2016; Tang et al. 2019). According to Fiorella and Mayer (2016), tracing can be considered to be one example of learning by enacting, meaning that task-relevant movements are integrated into the learning process, thereby fostering generative learning.

Secondly, haptic exploration may transmit information about an object’s material qualities, including texture, weight, consistency, and temperature (Minogue and Jones 2006). Lederman and Klatzky (1987) identified different exploratory procedures to classify stereotypical hand movements that adults use to explore objects with the haptic sense to obtain information on its properties. For example, the pressure was used to acquire information on the object’s hardness (Lederman and Klatzky 1987, 2009). These forms of exploration lead to a maximization of the sensory input and facilitate the encoding process. Accordingly, Montessori pedagogy has extended finger tracing by using sandpaper letters that provide additional tactile stimulation via the letters’ texture (Montessori 1912). This teaching technique involves input from several modalities at the same time to explore a letter: Students feel the way the letter is written while they touch and trace its contours, and at the same time, they look at its representation and listen to the sound of the letter pronounced by their teacher. Bara et al. (2004) found that using the haptic channel additionally increased the positive effects of the training on the decoding skills of children as well as their understanding and use of the alphabetic principle.

Thirdly, haptic exploration may provide detailed information about an object’s shape and the three-dimensional configuration of its parts. Particularly in science and medicine education, haptic interaction with three-dimensional models is used to foster comprehension of relevant spatial layouts, such as molecular configurations or anatomical structures. In a recent study, Stull et al. (2018) examined the impact of enactment with 3D molecular models on chemistry learning in video and classroom lectures. The students in both learning contexts learned more if they enacted the demonstration than if they just watched the demonstration. They also found that learning by enacting was stable over a period of several days between instruction and testing. Similarly, Smith (2016) used 3D-printed biological molecules as active learning tools to enhance learning in a lecture hall. The students reported the value of the models for understanding the learning contents and showed a high level of engagement during the learning session.

Acquiring Knowledge About Tools and Artifacts via Object-Based Learning

Taken together, haptic exploration should be considered a compound experience including motor stimulation, perception of material qualities, and information about shape and spatial configuration. While to date most of the empirical research on this topic has focused on abstract learning material, like molecular models, letters, or diagrams, similar effects have also been postulated for real objects. The pedagogical concept of object-based learning (OBL) posits that haptic interaction with real tangible objects can serve important roles in the learning process and encourages students to link these experiences to abstract ideas and concepts (Chatterjee et al. 2015; Rowe 2002). OBL is based on a multisensory, constructivist approach. By integrating haptics with other senses, such as vision and audition, it is assumed that learners develop their knowledge and understanding through interaction with objects. OBL is based on Kolb's experiential learning cycle (Kolb 1984), which—referring to Dewey (1899) and Piaget (1929)—links the four areas of (1) "concrete experience/feeling": a new experience is gained or an existing experience is reinterpreted; (2) "reflective observation of the experience"; (3) "abstract conceptualization/thinking": the reflection helps to raise a new idea or to modify an existing concept; (4) "active experimentation/doing": the new idea is applied, and the learner observes what happens. The learning cycle may be entered at each point, but the stages should be followed in sequence. As the name of the theory implies, the learner must be actively involved in the experience to acquire real knowledge. But also, the reflection on the experience and the use of analytical skills to conceptualize the experience is important to apply new knowledge. A qualitative study with semi-structured interviews showed that the combination of vision and the haptic sense led to higher levels of engagement and enhanced knowledge and understanding (Sharp et al. 2015). Tam (2015) conducted three case studies on OBL and showed that the haptic exploration of the objects led to a more intense learning experience. Students reported that touching sculptures feels more reliable than just seeing them, that it can enhance the understanding of the objects, and help to correct misconceptions.

OBL's emphasis on concrete haptic experiences with real objects seems to be particularly well suited for domains of knowledge in which human artifacts and tools play a prominent role, as is the case in many vocational fields. More specifically, haptic exploration may help users to detect affordances, that is, functional properties of artifacts in service of goal-directed actions (Gibson 1966, 1979). For example, simple mechanical interactions with hand-held tools allow users to judge their suitability for a diverse range of activities, like hammering, scraping, poking, or hooking (Harrison et al. 2011; Michaels et al. 2007).

While in Gibson's initial conception affordances are directly perceived without the necessity of internal representation, recent models assert that the knowledge of affordances can be stored in long-term memory and activated in subsequent contexts (Osiurak and Badets 2016). For example, Gredlein and Bjorklund (2005) found that children who engaged in manual play with a range of objects during free play were more successful in choosing appropriate tools for solving a task in a later situation. Furthermore, manipulation knowledge which is acquired by haptics and vision is linked to functional and mechanical knowledge (Remigereau et al. 2016). Whereas functional knowledge concerns information about the context in which a tool can be used together with the objects usually used with that tool, mechanical knowledge addresses the underlying physical and technical principles, allowing one to form a mental simulation of the tool use in action (Osiurak and Badets 2016; Remigereau et al. 2016). Taken together, according to current models of tool use, haptic exploration allows for generating manipulation knowledge, which, in concert with functional and mechanical knowledge, forms an embodied representation of one's knowledge about a given artifact or tool.

Most research in the field of tool use has dealt with simple, everyday tools (like hammers or knives) and can therefore be interpreted as a typical case of evolutionary evolved biologically primary knowledge (Geary 2008; Vaesen 2012), with learning taking place more or less playfully in an unconscious, effortless, rapid, and intrinsically motivated way. But in the light of instructional uses of embodied cognition (Geary 2008; Paas and Sweller 2012), making use of the mechanisms of biologically primary knowledge acquisition through the haptic exploration of material objects may also foster the learning of biologically secondary knowledge, particularly for contents that include information about unfamiliar tools or human artifacts.

Cognitive-Affective Theory of Learning with Media (CATLM) as a Framework for the Role of Haptics in Learning

The haptic exploration of objects in service of secondary learning normally takes place in concert with other types of learning materials, like verbal explanations, texts, or illustrations. Accordingly, the provision of touchable objects can be considered an extension of multimedia learning. Multimedia learning environments present information via various sensory channels, such as vision and audition, or via various sign systems, such as texts and illustrations (Mayer 2014). Several theories have been proposed that explain the cognitive learning effects of multimedia, mainly focusing on combinations of textual and pictorial material (Mayer 2014; Paas and Sweller 2014; Schnotz 2014).

The cognitive-affective theory of learning with media (CATLM, Moreno and Mayer 2007) extends these approaches in two ways. Firstly, it adopts the three basic assumptions of the cognitive theory of multimedia learning (Mayer 2014), namely: (1) information processing using two or more channels (Baddeley 1992; Paivio 1986), (2) the limited capacity of working memory (Sweller, 1999), and (3) active knowledge construction and active information processing as a prerequisite for successful learning (Mayer and Moreno 2003), but it supplements them with four additional assumptions, including (a) that long-term memory consists of a semantic and an episodic memory and has a dynamic structure (Tulving 1977), (b) that learning is mediated by motivational and affective factors by increasing or decreasing cognitive interrelations with the content (Pintrich 2003), (c) that metacognitive factors are supposed to influence learning with multimedia by regulating cognitive and affective processes (McGuinness 1990), and (d) that differences in prior knowledge and abilities of learners influence learning success (Kalyuga et al., 2003). Hence, CATLM explicitly takes the influence of motivational and affective factors and metacognition on learning with multimedia into account (Moreno and Mayer 2007).

Secondly, although CATLM emphasizes the importance of the auditive and the visual channel for accessing learning material, it also considers tactile, olfactory, and gustatory sensory input as additional information sources that may affect the learning process (Chan and Black 2006; Moreno and Mayer 2007). In addition, an emphasis is placed on the learners' interaction with the multimedia content, including manipulation of the presented material. Therefore, CATLM affirms the relevance of physical materials as a means for learning. This may include, for example, physical models in chemistry and medicine (Smith 2016; Stull et al. 2018), hands-on elements in Montessori pedagogy (Bara et al. 2004), or in science exhibitions (Afonso and Gilbert 2007; Skydsgaard et al. 2016) together with the recent development of digital force-feedback devices and 3D printing (Di Franco et al. 2015; Wilson et al. 2017) but also material objects like artifacts and tools (Chatterjee et al. 2015).

Both by introducing haptics into multimedia learning and by supplementing the core cognitive effects of multimedia material with possible effects on motivation, affect, and metacognition, CATLM provides a general framework for conceptualizing the role of haptics for learning experiences and learning outcomes. Therefore, we will discuss relevant empirical findings on the role of haptics for learning organized along with the components of the CATLM model: situational interest, attention and information selection, processing in working memory, storage in long-term memory, and affect.

Cognitive and Motivational Effects of Haptic Exploration

Situational Interest, Attention, and Information Selection

Studies on the effects of the provision of haptic exploration on situational interest and information selection have been primarily conducted in museum settings. In line with the assumption that acquiring biologically primary knowledge, for example, tool use, is intrinsically motivating, it was found that objects had both a higher attention catch and attention hold if they can be haptically explored (Di Franco et al. 2015; Koran et al. 1984; Wilson et al. 2017). Koran et al. (1984) showed an increase in the number of visitors entering the gallery when the exhibits could be haptically explored. Studies by Di Franco et al. (2015) and Wilson et al. (2017) found that museum visitors favored 3D prints and replica over original artifacts because the former allow for a haptic experience of the objects.

Research also indicates that haptics may be utilized to support the acquisition of secondary knowledge. For example, students of a biochemistry course identified touchable physical models as the most preferred and useful learning tools compared with other types of learning materials (Harris et al. 2009; Roberts et al. 2005). Also, Roberts et al. (2005) found that the availability of touchable models in a biochemistry course captured the students' interest in molecular structure and function, resulting in the formulation of more sophisticated questions on this topic. Therefore, in line with the assumptions of object-based learning, the haptic exploration of objects may constitute an initial step for approaching a certain topic, motivating learners to deal further with the subject (Chatterjee et al. 2015). Based on these findings, one can assume that objects which can be touched seem to attract attention and are preferred over objects which can be only looked at, that the increased interest in a topic can lead the learners to deal more intensively with the topic, and that they are motivated to engage in further information seeking on this topic.

Processing in Working Memory and Storage in Long-Term Memory

Recent studies demonstrate that haptic experiences of objects lead to detailed and durable long-term memory representations, indicating that touch constitutes an important sensory channel of environmental information on its own (Hutmacher and Kuhbandner 2018). Additionally, processing in working memory integrates haptic experiences with information from other sensory channels. According to Johnson et al. (1989), haptic inputs activate tactile representations, which in turn activate visual representations, in the case of familiar objects also triggering the object's name. Thus, in cases of fully compatible inputs from vision and haptics, as when an object is looked at while touching it, a unified, multimodal representation is built (Hollins 2010). Accordingly, cross-modal recognition tests show high degrees of accuracy in recognizing objects visually after participants were blindfolded and had explored the objects with their hands (Hutmacher and Kuhbandner 2018; Lacey and Sathian 2014).

Due to its nature as a source of biologically primary knowledge, the use of the haptic sense may reduce the cognitive load required for the acquisition of biologically secondary knowledge (Paas and Sweller 2012). Similarly, according to the embedded cognition claim, perceptual and interactive richness of haptic experiences may alleviate the cognitive load by embedding the learner's cognitive activity in the environment (Pouw et al. 2014). Also, some authors have argued further that the permanent availability of haptic information during learning can be seen as an instance of cognitive offloading, thereby reducing extraneous cognitive load and freeing working memory resources for enhanced elaboration (Manches and Malley 2012; Pouw et al. 2014). Empirical research on finger tracing showed mixed results concerning the positive effect of tracing on cognitive load. While some studies failed to show a reduction in perceived cognitive load through tracing (Agostinho et al. 2015; Ginns et al. 2016; Korbach et al. 2020; Macken and Ginns 2014), other studies found that tracing can have a positive effect on test item difficulty ratings, which can be interpreted as a measurement of intrinsic cognitive load (Du and Zhang 2019; Hu et al. 2015; Yeo and Tzeng 2019). In a recent study, it was found that primary school students who traced while studying learning material about the water cycle showed lower extraneous—but not intrinsic—cognitive load than students who were not allowed to trace (Tang et al. 2019).

Finally, while it has been argued that the perceptual richness of objects may hinder the learners' ability to identify intended underlying principles or symbolic meanings (Kaminski et al. 2009; Uttal et al. 2009), this view has been criticized from the perspective of embodied cognition accounts (Pouw et al. 2014). In particular, it has been argued that learning from manipulatives often includes internalization of sensorimotor routines without a change from concrete to abstract representation, as long as the information provided by manual exploration stands in close relationship to the abstract contents to be learned. For example, a recent study by Bara and Kaminski (2019) found that children who held objects in their hands while learning the corresponding foreign language vocabulary memorized the words better than those who saw the respective pictures of the objects during learning. This close relationship between sensorimotor and semantic information is particularly evident for the acquisition of knowledge about tools and artifacts. As has been discussed above, during learning, the manipulation knowledge that is acquired by haptics and vision is linked to functional knowledge about the contexts and conditions of using the respective artifact (Remigereau et al. 2016). Hence, taken together, the findings indicate that haptic exploration contributes to a rich multimodal representation which may also be linked to abstract concepts, thereby facilitating retention and transfer.

Affect

Although CATLM also considers the affective effects of multimedia learning materials, to the best of our knowledge, systematic research on affective effects of haptic exploration in educational contexts is virtually absent. Yet, findings in the field of consumer research have shown that affective responses can be evoked by the sensory feedback elicited by the act of touching (Peck and Shu 2009; Peck and Wiggins 2006). Peck and Childers (2003) pointed out that especially individuals with a high need for touch consider touch to be a way to experience pleasure and enjoyment and engage in touch because it is fun, interesting, and enjoyable. Etzi et al. (2016) found that different tactile textures are associated with words expressing different emotional states. Some studies have shown that touching certain objects (e.g., honey or worms) can induce the feeling of unpleasantness and disgust (Oum et al. 2011; Skolnick 2013). The results of these studies thus indicate that, depending on the type of object, haptic exploration can evoke and intensify either positive or negative affective reactions.

The Present Study

The previous discussion indicates that, in line with the assumptions of CATLM, the haptic exploration of real objects, like tools and artifacts, can have a positive impact on situational interest and the selection of information, and on the processing in working memory, including integration with other sensory modalities as well as more abstract information. This positive impact also extends to storage in long-term memory and to motivation to deal further with the subject matter exemplified by the objects. Therefore, the present study used a multi-criteria approach to investigate the influence of haptic exploration of real objects on learning experience and learning outcomes. A museum context was chosen because it is characterized by the self-determination and the intrinsic motivation of learners and is thus particularly useful for the investigation of motivational and cognitive learning effects (Lewalter and Geyer 2009; Schwan et al. 2014). As part of a larger project on the presentation of conflicting issues in exhibitions, we set up an experimental exhibition on the topic "animal husbandry, breeding, and welfare" which consisted of two showrooms. In the first showroom, the sensory access of the participants to the exhibition objects, consisting of six tools typical of animal husbandry and breeding, was systematically varied in a 2 × 2 design with the between-subjects factors vision (yes: objects visible/no: objects not visible) and haptics (yes: objects touchable/no: objects not touchable). To provide a rich multimodal learning experience, all of the participants were provided with additional information about each tool via an audio guide. In a second showroom, further information on themes related to the tools was presented using posters with texts, illustrations, and diagrams. The second showroom was the same for every participant. We aimed to investigate whether the haptic experience in the first showroom served as a motivator to engage further with the topic.

Referring to CATLM (Moreno and Mayer 2007), we hypothesized that the more sensory channels are used during knowledge acquisition, the more intense the engagement with the learning content should be. Thus, touching objects while looking at the object was expected to be better than touching them without vision or looking at them without touching, which in turn should be better than neither seeing nor touching the objects. In particular, we assumed (1) a heightened attention catch and attention hold of the objects, which should be shown by an increased duration of stay (length of time spent in each showroom), an increased number of objects inspected, and an increased situational interest in the first showroom, and (2) we assumed an increase in memory for the objects and a better performance in a knowledge acquisition test that should appear (a) directly after the exhibition and (b) in a follow-up. We also hypothesized a transfer of the beneficial effects of haptic exploration in the second showroom, which should manifest in (3) an increased duration of stay, an increased number of posters read, and a greater situational interest in the second showroom together with (4) a better comprehension of the contents of its textual material. In addition, we investigated the affective differences between the experimental groups during the exploration of the two showrooms. We assumed that the participants who could touch objects in the first showroom will report more intensive affective states than the participants who were not allowed to touch the objects (5).

Method

Participants

Participants were recruited from our institute's mailing list. They were required to be native German speakers. Assuming medium effect sizes and a power of .80, a power analysis using GPower recommended sample size of $n = 158$ participants. We decided to recruit 160 participants (40 per condition). Excluded participants were replaced by other participants. From the 174 recruited participants, eleven had to be excluded because they had not followed the instructions properly or because of technical difficulties. The remaining 163 participants ranged in age between 18 and 66 years ($M = 24.76$, SD = 7.55); 120 of them (73.6%) were female, 42 (25.8%) were male, and one (0.06%) was diverse (non-binary). Most of the participants (93.3%) were students from a broad variety of disciplines. The research was approved by the institutional review board of our institute. All of the participants provided written informed consent before participating in this study and were paid for their participation.

Design

We used a 2 × 2 between-subjects design with the factors vision (yes/no) and haptics (yes/no). The participants were randomly assigned to one of the four experimental conditions: no-object condition ($n = 42$), only-vision condition ($n = 40$), only-haptics condition ($n = 42$), and vision-and-haptics condition ($n = 39$). Three weeks after visiting the experimental exhibition, the participants were requested to fill out an online survey as a follow-up. A total of 115 participants took part in this follow-up (no-object condition, $n = 29$; only-vision condition, $n = 27$; only-haptics condition, $n = 29$; vision-and-haptics condition, $n = 30$).

Materials

Showroom 1 In the first showroom, methods used in conventional dairy cow and pig farming were both demonstrated with the help of three tools that are typically used in animal husbandry and breeding, namely, a milking machine, an insemination gun with a veterinary glove, and a dehorning device for cow farming, and castration forceps, a massage brush, and a heat cutter for pig farming (see Fig. 1). The tools were complex tools that are not commonplace and unknown to most people. In the only-vision condition and the vision-and-haptics condition, the objects were put on museum pedestals. In the only-haptics condition, the objects on the pedestals were put into feeler boxes to ensure that the objects could be touched but not seen by the participants. In the no-objects condition, the museum pedestals remained empty. To remind the participants of the corresponding instruction, we had signs—similar to those in a museum—hung up: "Please do not touch," "Please touch," and "Feel it." In order to address the auditory channel, all of the participants were provided with information about each exhibit via an audio guide. The auditory device was completely controllable by participants. They could start, stop, fast forward, and rewind the audio texts. The six audio texts lasted about 2 min each.

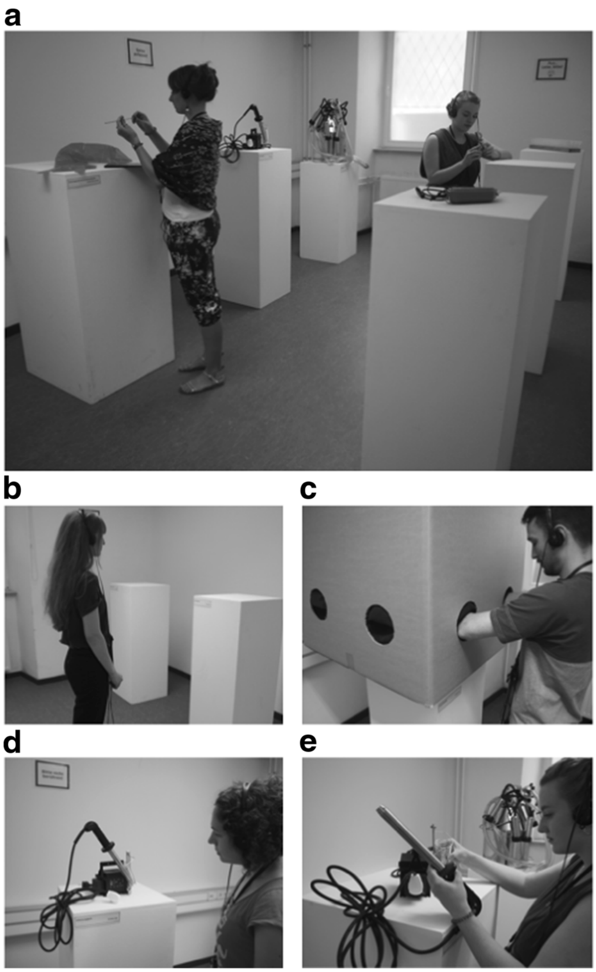

Fig. 1 In the first showroom, tools that are typically used in animal husbandry and breeding were presented. **a** Overview of the first showroom in the vision-and-haptics condition; **b** participant in the no-objects condition; **c** participant in the only-haptics condition; **d** participant in the only-vision condition; **e** participant in the vision-and-haptics condition

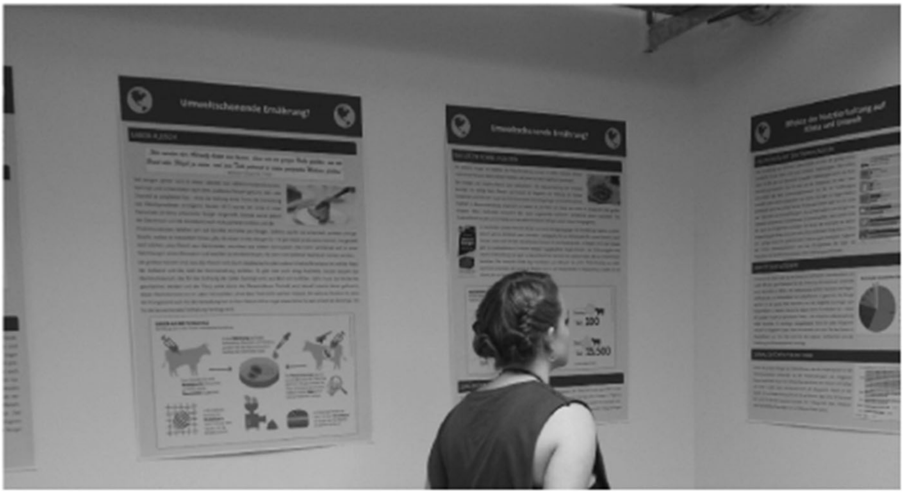

Fig. 2 In the second showroom, posters with further information on animal husbandry and breeding were presented

Showroom 2 For each object, further information on a related topic was provided by posters in the second showroom (see Fig. 2; e.g., showroom 1: a milking machine and an audio text about the history and use of milking machines were presented; showroom 2: the life of a dairy cow was explained). We also presented four posters with more general topics (nutrition, climate, and environment). In total, we presented twelve posters which were vividly designed using a combination of texts, illustrations, and diagrams.

Measures

The participants were asked to fill out questionnaires on an iPad mini before visiting the first showroom, after visiting the first showroom, and after visiting the second showroom. The follow-up was conducted via a Qualtrics online survey and could be filled out at home. The following scales and tests were used:

Self-reported Prior Knowledge

Seven items answered on a 5-point Likert-type scale (1 "not at all" to 5 "very well"; e.g., "How well are you acquainted with the following topics? – livestock husbandry") asked the participants how good they self-evaluate their knowledge on different aspects of the exhibition's topic. An average prior knowledge score was calculated from the sum of all responses divided by the total number of items (Cronbach's $\alpha = .874$).

Prior Interest

Prior thematic interest in the topic of the exhibition was measured by four items on a 5-point Likert-type scale (1 "not at all" to 5 "very"; e.g., "I am interested in the topic of livestock husbandry."). An average interest score was calculated by the sum of all responses divided by the total number of items (Cronbach's $\alpha = .844$).

Attention and Information Selection

In the museum context, attention and information selection is often operationalized by attention catch (What is observed?) and by attention hold (How long is it observed?) (Serrell 1997). In addition to direct observation or measuring the duration of stay, questionnaires can be used to measure attention catch and attention hold (Lewalter and Geyer 2009). Accordingly, three indicators were collected in our study: the duration of stay, the number of objects inspected in the first showroom (posters in the second showroom), and a German scale on situational interest (Lewalter and Geyer 2009). In the model of Hidi and Renninger (2006), situational interest constitutes a first step in the development of interest by becoming spontaneously attracted to certain content. According to Lewalter and Geyer (2009), two phases of situational interest can be distinguished: (1) SI-catch in which attention of a person is drawn and curiosity is aroused, and (2) SI-hold which describes the intention to maintain attention to the contents and spend more time on them (Hidi and Renninger 2006; Lewalter and Geyer 2009). We collected these variables for the first and the second showroom. Whereas the results of the first showroom served as indicators for differences in attention and information selection processes, the results of the second showroom indicated whether the participants differ in their motivation to engage themselves with further information on the exhibition topic due to their experience in the first showroom.

Number of Objects Inspected and Posters Read After each showroom, we asked the participants to indicate on a plan of the showroom which of the exhibition contents they had inspected. In both conditions in which touching was allowed, we asked them to indicate whether they had touched the tools in the first showroom. If they had touched fewer than four objects, they were excluded from the analysis. In the only-vision condition, the participants were asked to indicate whether they had touched the tools. If they had touched more than two objects, they were excluded from the analysis.

Duration of Stay The observation time in both showrooms was measured by the iPad mini.

Situational Interest (Attention Catch and Attention Hold) We used an adapted German scale for situational interest (Knogler et al. 2015; Lewalter and Geyer 2009; Lewalter 2020) which distinguishes between the two phases of situational interest: (1) SI-catch, and (2) SI-hold. Accordingly, the scale included two subscales with six 5-point Likert-type scale (1 “not at all” to 5 “very much”) items each for attention catch (e.g., “The exhibition captivated my attention.”) and attention hold (e.g., “I would like to know more about parts of the exhibition.”). Due to the strong correlation between both subscales ($r = .596$, $p = 0.01$), we analyzed them as one scale. We measured situational interest after the first showroom (Cronbach’s $\alpha = .893$) and after the second showroom (Cronbach’s $\alpha = .910$).

Recall of Objects

We asked the participants to list all of the objects of the first showroom. An answer was considered correct if the participants listed the correct name or if it was clear from the description that the function of the tools was understood. A total of six points could be achieved. The evaluator of the recalled objects was blinded to the experimental condition. Ten percent of the answers were randomly chosen and rated by two independent raters. The inter-rater agreement was 97.45%.

Knowledge Acquisition Test

In the knowledge acquisition test, 32 self-developed multiple-choice questions with four response options (one correct) were asked (e.g., “Approximately how old is a dairy cow when she is inseminated for the first time?” – (a) 12 months, (b) 16 months, (c) 24 months, (d) 28 months; “What is the procedure for dehorning?” (a) The roots of the horns are pinched off with pliers, (b) The roots of the horns are sawn off, (c) The horn buds are cut away, (d) The horn buds are removed by heat; “Which tool is used to cut the curly tails?” (a) pliers, (b) heat cutter, (c) scalpel, (d) scissors.) Twelve questions addressed the first showroom, and 20 questions addressed the second showroom. We used the knowledge acquisition test in the second posttest (directly after visiting the exhibition) and in the follow-up (3 weeks after visiting the exhibition). While the internal consistency of the knowledge acquisition test concerning the first showroom was low (Cronbach’s $\alpha_{\text{after exhibition}} = .342$ and Cronbach’s $\alpha_{\text{follow-up}} = .331$), the internal consistency of the knowledge acquisition test concerning the second showroom was acceptable (Cronbach’s $\alpha_{\text{after exhibition}} = .703$ and Cronbach’s $\alpha_{\text{follow-up}} = .652$).

Need for Touch

To access the individual preference for haptic information, we used a German version (Nuszbaum et al. 2010) of the need for touch (NFT) scale by Peck and Childers (2003). It consisted of 14 items answered on a 5-point Likert-type scale (1 “not at all” to 5 “very much”; e.g., “When walking through stores, I can’t help touching all kinds of products.”). An average score for the need for touch was calculated by the sum of all responses divided by the total number of items (Cronbach’s $\alpha = .950$).

The Composite Respect for Animals Scale

To measure attitude towards animals and the use of them, we used six components of the short version of the German Composite Respect for Animals Scale (CRAS-S; Randler et al. 2018). Each component was measured by two items on a 5-point Likert-type scale (1 “fully agree” to 5 “fully disagree,” e.g., “I think it is perfectly acceptable for animals to be raised for human consumption.”). Since one item was excluded due to a bad item characteristic ($r = .162$), the construct was measured by 11 items, and an average score was calculated by the sum of all responses divided by the total number of items (Cronbach’s $\alpha = .793$).

Positive Affect and Negative Affect Schedule

The participants’ affective states were measured with the German version of the Positive Affect and Negative Affect Schedule (PANAS; Breyer and Bluemke 2016; Watson et al. 1988) which consists of ten items for positive (e.g., “enthusiastic,” “inspired”) and ten items for negative affect (e.g., “upset,” “ashamed”). Both positive and negative affect were measured on a 5-point Likert-type scale (1 “not at all” to 5 “extremely”). We used the PANAS before the exhibition, after the first and after the second showroom. Two average scores (for positive and negative affect) were calculated by the sum of all responses divided by the total number of items (positive affect: Cronbach's $\alpha_{\text{before exhibition}} = .853$, Cronbach's $\alpha_{\text{after showroom 1}} = .792$, Cronbach's $\alpha_{\text{after showroom 2}} = .829$; negative affect: Cronbach's $\alpha_{\text{before exhibition}} = .819$, Cronbach's $\alpha_{\text{after showroom 1}} = .886$, Cronbach's $\alpha_{\text{after showroom 2}} = .882$).

Procedure

After reading the information about the study and signing the informed consent, the participants were asked to fill out the PANAS, the prior knowledge test, and the prior interest scale. Then, they were invited to visit the first showroom and explore it freely at their own pace and interest. The participants were instructed to leave their personal belongings, like coats, bags, and smartphones in the room where the surveys took place. Depending on the experimental condition, they were instructed to either touch and explore or not to touch the objects. The participants in the no-objects condition were informed that it had not been possible to procure the objects. All of the participants were instructed to use the iPad as an audio guide for each exhibit in the first showroom. Following the visit, the participants were then asked to fill out the PANAS and the situational interest scale and to indicate which tools they had inspected.

Next, the participants were led to the second showroom and were asked to explore this room at their own pace and interest. After that, the participants were asked to fill out the PANAS and the situational interest scale and to indicate which posters they had read. After playing cards for about 10 min as a filler task, the participants were asked to freely recall all of the objects that were presented in the first showroom, to fill out a knowledge acquisition test, the NFT, the CRAS-S, and questions on their sociodemographic data. The study lasted 1 to 1.5 h for each participant. The participants began the study every quarter of an hour so that they were either alone, in pairs, or in threes in one of the two exhibition rooms.

After 3 weeks, the participants were invited by e-mail to fill out the follow-up online survey, which included a self-evaluation of their knowledge and thematic interest, recalling the objects that were presented in the first showroom, and again completing the knowledge acquisition test. The completion of the online survey took about 10 min.

Results

A Priori Differences Between Groups

The participants reported a medium level of prior knowledge ($M = 2.62$, SD = 0.67) and interest ($M = 3.15$, SD = 0.85), a rather pro-animal attitude towards the use of animals ($M = 3.45$, SD = 0.60) and a medium score for the need for touch ($M = 2.48$, SD = 0.90; see Table 1). A series of two-way ANOVAs with vision and haptics as between-subjects factors showed no statistically significant differences in attitude towards the use of animals and need for touch, all $F < 2.6$, all $p > .05$.

The two-way ANOVA with self-evaluated prior knowledge as a dependent variable revealed no significant main effects of vision, $F(1,159) = 0.003$, $p = .956$, $\eta_p^2 < 0.01$, and haptics, $F(1,159) = 2.25$, $p = .136$, $\eta_p^2 = 0.01$, but a significant interaction between those two factors, $F(1,159) = 6.16$, $p = .014$, $\eta_p^2 = 0.04$. Subsequent post hoc tests (Tukey's HSD) revealed that

Table 1 Means and standard deviations for control variables

	No-objects condition *M* (*SD*)	Only-vision condition *M* (*SD*)	Only-haptics condition *M* (*SD*)	Vision-and-haptics condition *M* (*SD*)
CRAS-S*	3.53 (0.68)	3.44 (0.55)	3.35 (0.57)	3.47 (0.59)
Need for touch	2.38 (0.89)	2.36 (0.84)	2.74 (1.02)	2.44 (0.82)
Prior knowledge	2.83 (0.65)	2.56 (0.67)	2.42 (0.63)	2.67 (0.70)
Prior interest	3.32 (0.91)	3.02 (0.86)	2.95 (0.83)	3.33 (0.73)

*CRAS-S: the Composite Respect for Animals Scale

the participants in the no-objects condition rated their prior knowledge higher than the participants in the only-haptics condition.

The two-way ANOVA with self-evaluated prior interest as a dependent variable revealed no significant main effects of vision, $F(1,159) = 0.08$, $p = .779$, $\eta_p^2 < 0.01$, and haptics, $F(1,159) = 0.11$, $p = .738$, $\eta_p^2 = 0.01$, but a significant interaction between those two factors, $F(1,159) = 6.76$, $p = .010$, $\eta_p^2 = 0.04$. Subsequent post hoc tests (Tukey's HSD) showed no significant differences in the experimental groups.

Due to the significant results regarding prior knowledge and interest, we included these variables as covariates in the following analysis. Due to multiple comparisons, we conducted a Bonferroni correction for the following analysis. The adjusted α value is 0.004. To determine if any of the comparisons are statistically significant, the p value must be $p < 0.004$.

Situational Interest, Attention, and Information Selection

Duration of Stay in the First Showroom The average duration of stay in the first showroom was just under a quarter of an hour ($M = 14.40$, SD = 1.91). To test whether the groups differed in the time that they spent in the first showroom, we conducted a two-way ANCOVA with the between-subjects factors vision and haptics on the duration of stay, controlling for prior knowledge and prior interest. There were no significant differences in the duration of stay between the experimental groups in the first showroom, all $F < 3.3$.

Number of Objects Inspected Most of the participants dealt with all of the objects and the corresponding audio texts in the first showroom ($M = 5.72$, SD = 1.11). According to a two-way ANCOVA with the between-subjects factors vision and haptics, controlling for prior knowledge and prior interest, there were neither significant differences between the experimental groups nor significant effects of the covariates, all $F < 1.1$.

Situational Interest (Attention Catch and Attention Hold) The participants showed a medium to a high level of attention catch and hold, as measured by the situational interest questionnaire after visiting the first showroom ($M = 3.66$, SD = 0.65). After controlling for prior knowledge, $F(1,157) = 0.92$, $p = .340$, $\eta_p^2 = 0.01$, and prior interest, $F(1,157) = 53.56$, $p < .001$ $\eta_p^2 = 0.25$, we found no significant main effect for vision, $F(1,157) = 0.27$, $p = .606$, $\eta_p^2 < 0.01$, and no significant main effect for haptics, $F(1,157) = 4.19$, $p = .042$, $\eta_p^2 = 0.03$. There was no significant interaction effect, $F(1,157) = 0.28$, $p = .598$, $\eta_p^2 < 0.01$. Means and standard deviations of all attentional variables are shown in Table 2.

Table 2 Means and standard deviations for the duration of stay, number of objects inspected, and situational interest in the first showroom

	No-objects condition *M* (*SD*)	Only-vision condition *M* (*SD*)	Only-haptics condition *M* (*SD*)	Vision-and-haptics condition *M* (*SD*)
Duration of stay	14.04 (1.36)	14.27 (2.12)	14.62 (1.95)	14.68 (2.11)
Number of objects inspected	5.88 (0.77)	5.72 (1.04)	5.52 (1.49)	5.77 (1.01)
Situational interest	3.63 (0.58)	3.51 (0.78)	3.65 (0.60)	3.87 (0.61)

Information Processing

Recall of Objects

Recall of the exhibited objects was measured at two points: directly after visiting the exhibition and 3 weeks after visiting the exhibition. Since 29.6% of the participants did not take part in the follow-up, we analyzed the results of both measurement points separately.

Directly After Visiting the Exhibition In the second posttest, we asked the participants to write down all of the objects presented in the first showroom that they could remember. On average, the participants remembered 4.27 (SD = 1.27) out of 6 objects. After controlling for prior knowledge, $F(1,157) = 0.45$, $p = 0.505$, $\eta_p^2 < 0.01$, and prior interest, $F(1,157) = 1.24$, $p = 0.266$, $\eta_p^2 < 0.01$, we found significant main effects for vision, $F(1,157) = 15.40$, $p < .001$, $\eta_p^2 = 0.09$, and haptics, $F(1,157) = 13.98$, $p < .001$, $\eta_p^2 = 0.08$. The interaction effect between those two factors was not significant, $F(1,157) = 6.96$, $p = .009$, $\eta_p^2 = 0.04$. Subsequent post hoc tests (Tukey's HSD) showed that the participants in the no-objects condition remembered significantly fewer objects than participants in the other conditions, while there were no differences between the other experimental groups (see Fig. 3).

Follow-up In the follow-up survey, we asked the participants again to write down all of the objects presented in the first showroom that they could remember. On average, the participants remembered 3.15 (SD = 1.52) out of 6 objects. After controlling for prior knowledge, $F(1,109) = 7.29$, $p < .008$, $\eta_p^2 = 0.06$, and prior interest, $F(1,109) = 2.09$, $p = .151$, $\eta_p^2 = 0.02$, we found significant main effects for vision, $F(1,109) = 9.52$, $p = .003$, $\eta_p^2 = 0.08$, and haptics, $F(1,109) = 27.10$, $p < .001$, $\eta_p^2 = 0.20$, but no significant interaction effect, $F(1,109) = 2.98$, $p = .087$, $\eta_p^2 = 0.03$. Post hoc tests (Tukey's HSD) showed that the participants in the no-objects condition remembered significantly fewer objects than the participants in the other conditions and that participants in the only-vision condition remembered significantly fewer objects than the participants in the vision-and-haptics condition. There were no significant differences between the only-haptics and the vision-and-haptics condition and the only-haptics and the only-vision condition (see Fig. 3).

Knowledge Acquisition Test Concerning the First Showroom

The participants were asked to take the test at two measurement points: directly after visiting the exhibition and 3 weeks after visiting the exhibition in the follow-up. Since the questions on

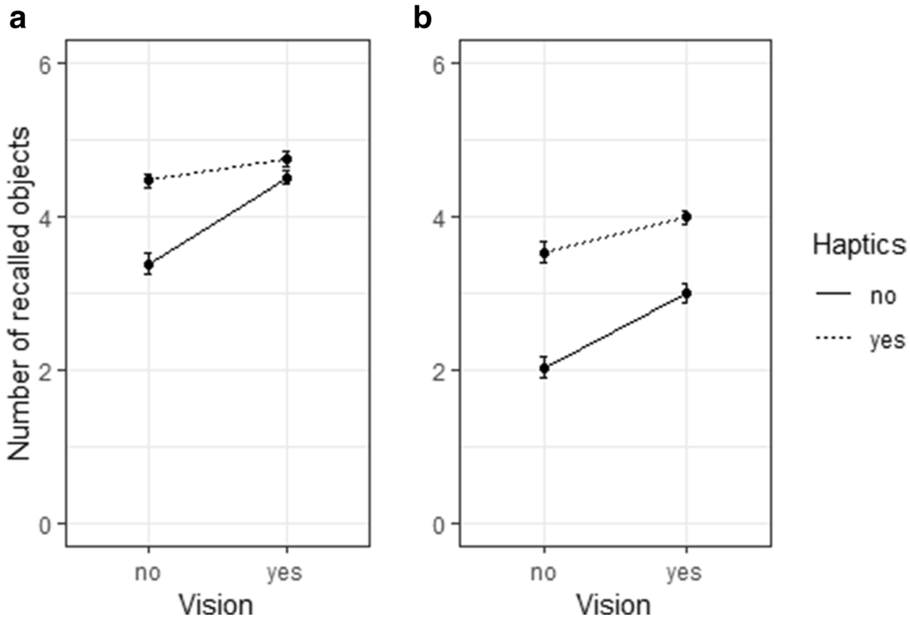

Fig. 3 Scores in the free recall **a** directly after the exhibition and **b** in the follow-up. Error bars represent the standard error

the objects were difficult (virtually impossible) to answer for the no-objects condition, the following analysis was only run for the other three experimental conditions.

Directly After the Exhibition On average, the participants answered 7.36 (SD = 1.70) out of 12 questions correctly. After controlling for prior knowledge, $F(1,115) = 0.01$, $p = .930$, $\eta_p^2 <$ 0.01, prior interest, $F(1,115) = 1.33$, $p = 0.251$, $\eta_p^2 = 0.01$, and the number of objects inspected in the first showroom, $F(1,115) = 4.05$, $p = .047$, $\eta_p^2 = 0.03$, a one-way ANCOVA with the condition (only-haptics, only-vision, vision-and-haptics) as a between-subjects factor revealed a significant main effect, $F(1,115) = 6.89$, $p = .001$, $\eta_p^2 = 0.11$. Post hoc tests (Tukey's HSD) revealed better retention in the haptics-and-vision condition ($M = 7.82$, SD = 1.54) and in the only-vision condition ($M = 7.70$, SD = 1.81) than in the only-haptics condition ($M = 6.62$, SD = 1.53).

Follow-up In the follow-up, the participants answered on average 7.32 (SD = 1.53) out of 12 questions correctly. After controlling for prior knowledge, $F(1,80) = 0.69$, $p = .410$, $\eta_p^2 = 0.01$, prior interest, $F(1,80) = 1.86$, $p = .180$, $\eta_p^2 = 0.02$, and a number of objects inspected in the first showroom, $F(1,80) = 0.46$, $p = .498$, $\eta_p^2 = 0.01$, we found no significant main effect for condition, $F(1, 80) = 5.10$, $p = .008$, $\eta_p^2 = 0.11$.

Second Showroom: Behavior, Interest, and Knowledge Acquisition

The behavior and the outcomes in the second showroom serve as indicators for the participants' motivation to engage themselves with further information on the topic after visiting the first showroom, in which different sensory experiences were available.

Table 3 Means and standard deviations for the duration of stay, number of posters read, and situational interest in the second showroom

	No-objects condition *M* (*SD*)	Only-vision condition *M* (*SD*)	Only-haptics condition *M* (*SD*)	Vision-and-haptics condition *M* (*SD*)
Duration of stay	20.62 (4.78)	21.06 (7.70)	20.59 (5.67)	22.41 (6.05)
Number of posters read	11.86 (0.42)	11.20 (2.23)	11.00 (2.67)	11.56 (1.86)
Situational interest	3.94 (0.66)	3.76 (0.72)	3.68 (0.70)	3.95 (0.50)

Duration of Stay in the Second Showroom

The average duration of stay in the second showroom was just over 20 min ($M = 21.14$, SD = 6.11; see Table 3). Controlling for prior knowledge and prior interest, a two-way ANCOVA with the between-subjects factors vision and haptics showed no significant effects on the duration of stay in the second showroom, all $F < 7.5$.

Number of Posters Read

Most of the participants read all of the posters in the second showroom ($M = 11.04$, SD = 1.99; see Table 3). A two-way ANCOVA with the between-subjects factors vision and haptics, controlling for prior knowledge and prior interest, revealed neither significant differences between the experimental groups nor significant effects of the covariates, all $F < 3.5$.

Situational Interest (Attention Catch and Hold)

After visiting the second showroom, the participants showed a high level of attention catch and hold measured by situational interest ($M = 3.83$, SD = 0.66; see Table 3). After controlling for prior knowledge, $F(1,157) = 0.23$, $p = .630$, $\eta_p^2 < 0.01$, and prior interest, $F(1,157) = 62.22$, $p < .001$, $\eta_p^2 = 0.28$, an ANCOVA showed no significant main effect for vision, $F(1,157) = 0.16$, $p = .687$, $\eta_p^2 < 0.01$, and haptics, $F(1,157) = 0.22$, $p = .638$, $\eta_p^2 < 0.01$, and no significant interaction effect, $F(1,157) = 0.86$, $p = .356$, $\eta_p^2 = 0.01$.

Knowledge Acquisition Test Concerning the Second Showroom

We measured knowledge acquisition at two measurement points: directly after visiting the exhibition and 3 weeks after visiting the exhibition in the follow-up.

Directly After Visiting the Exhibition On average, the participants answered 14.33 (SD = 3.23) out of 20 questions correctly (see Table 4). After controlling for prior knowledge, $F(1,156) = 6.92$, $p = 0.009$, $\eta_p^2 = 0.04$, prior interest, $F(1,156) = 5.29$, $p = .022$, $\eta_p^2 = 0.03$, and a number of posters read in the second showroom, $F(1,156) = 8.76$, $p = .004$, $\eta_p^2 = 0.05$, an ANCOVA showed no significant main effects for vision, $F(1,156) = 0.01$, $p = .912$, $\eta_p^2 < 0.01$, and haptics, $F(1,156) = 0.45$, $p = 0.502$, $\eta_p^2 < 0.01$, and no significant interaction between those factors, $F(1,156) = 2.59$, $p = 0.109$, $\eta_p^2 = 0.02$.

Table 4 Means and standard deviations for the knowledge acquisition test for both measurement points

	No-objects condition *M* (*SD*)	Only-vision condition *M* (*SD*)	Only-haptics condition *M* (*SD*)	Vision-and-haptics condition *M* (*SD*)
After the exhibition	14.83 (2.70)	13.48 (3.67)	13.88 (3.64)	15.15 (2.55)
Follow-up	13.28 (2.95)	12.41 (3.20)	11.69 (3.19)	13.20 (2.98)

Follow-up In the follow-up, the participants answered 12.65 (SD = 3.11) out of questions correctly on average (see Table 4). After controlling for prior knowledge, $F(1,108) = 1.73$, $p = .191$, $\eta_p^2 = 0.02$, prior interest, $F(1,108) = 0.50$, $p = .486$, $\eta_p^2 = 0.01$, and a number of posters read in the second showroom, $F(1,108) = 10.17$, $p = .002$, $\eta_p^2 = 0.09$, an ANCOVA showed no significant main effects for vision, $F(1,108) = 0.38$, $p = .541$, $\eta_p^2 < 0.01$, and haptics, $F(1,108) = 0.54$, $p = .466$, $\eta_p^2 = 0.01$, and no interaction between those factors, $F(1,108) = 1.57$, $p = 0.214$, $\eta_p^2 = 0.01$.

Differences in Affect in Both Showrooms

Both positive and negative affect were measured before the participants visited the exhibition, after visiting the first showroom, and after visiting the second showroom.

Positive Affect A three-way ANOVA with the between-subjects factors vision and haptics and the within factor showroom revealed no significant main effects for the factor vision, $F(1,159) = 0.004$, $p = .952$, $\eta_p^2 < 0.01$, and haptics, $F(1,159) = 0.01$, $p = .910$, $\eta_p^2 < 0.01$, but a significant main effect of the factor showroom, $F(2,318) = 58.38$, $p < .001$, $\eta_p^2 = 0.27$. There was no significant interaction between vision and haptics, $F(1,159) = 0.02$, $p = .902$, $\eta_p^2 < 0.01$, vision and showroom, $F(2,318) = 0.46$, $p = .629$, $\eta_p^2 < 0.01$, and haptics and showroom, $F(2,318) = 0.51$, $p = .599$, $\eta_p^2 < 0.01$. The three-way interaction was not significant, $F(2,318) = 5.74$, $p = .004$, $\eta_p^2 = 0.04$. Means and standard deviations are shown in Table 5.

Negative Affect A three-way ANOVA with the between-subjects factors vision and haptics and the within-subject factor showroom showed no significant main effects for vision, $F(1,159) = 1.74$, $p = .189$, $\eta_p^2 = 0.01$, and haptics, $F(1,159) = 1.23$, $p = .270$, $\eta_p^2 = 0.01$, but a significant main effect for factor showroom, $F(2,318) = 147.24$, $p < .001$, $\eta_p^2 = 0.48$. There was

Table 5 Means and standard deviations for positive and negative affect before visiting the exhibition and after visiting the first and the second showroom

		No-objects condition *M* (*SD*)	Only-vision condition *M* (*SD*)	Only-haptics condition *M* (*SD*)	Vision-and-haptics condition *M* (*SD*)
Positive affect	Before exhibition	3.00 (0.64)	3.19 (0.61)	3.14 (0.61)	3.05 (0.56)
	After showroom 1	2.72 (0.60)	2.68 (0.53)	2.71 (0.46)	2.75 (0.55)
	After showroom 2	2.82 (0.64)	2.67 (0.51)	2.64 (0.64)	2.75 (0.61)
Negative affect	Before exhibition	1.24 (0.36)	1.43 (0.49)	1.35 (0.36)	1.21 (0.29)
	After showroom 1	1.81 (0.59)	1.99 (0.60)	2.12 (0.68)	2.23 (0.84)
	After showroom 2	1.83 (0.69)	2.12 (0.64)	2.00 (0.62)	1.98 (0.76)

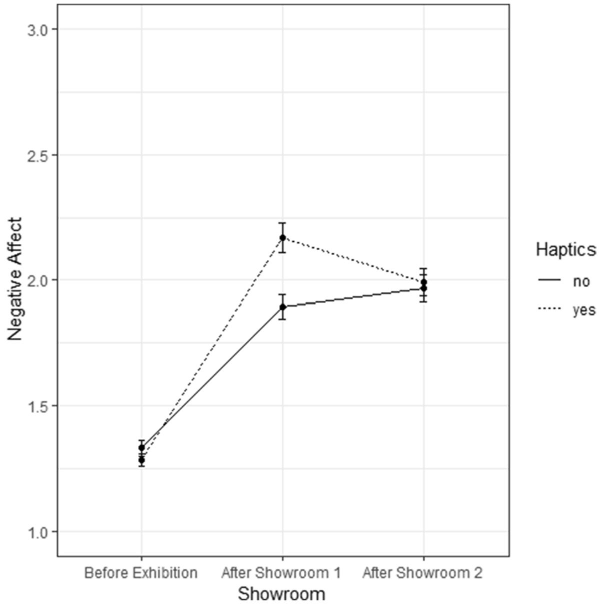

Fig. 4 Interaction effect between the factors haptics and showroom concerning the negative affect (measured on a 5-point Likert-type scale). Error bars represent the standard error

no significant interaction between vision and haptics, $F(1,159) = 2.36$, $p = .126$, $\eta_p^2 = 0.02$, and vision and showroom, $F(2,318) = 0.88$, $p = .416$, $\eta_p^2 = 0.01$, but a significant interaction between haptics and showroom, $F(2,318) = 6.57$, $p = .002$, $\eta_p^2 = 0.04$ (see Fig. 4). Compared with the negative affect before visiting the exhibition, the negative affect increased for all groups after visiting the first showroom. The increase was greater for the participants who were allowed to touch the objects than for the participants who were not allowed to touch them. After visiting the second showroom, there were no group differences in negative affect (see Table 5). There was no significant three-way interaction, $F(2,318) = 1.13$, $p = .324$, $\eta_p^2 = 0.01$.

Discussion

Current theories of embodied cognition posit that the haptic sense complements vision and hearing by a bodily exploration of physical entities in our close surroundings, thus contributing to the formation of enriched mental representations. Haptic exploratory routines constitute an integral part of a human's behavioral repertoire. These routines develop early in childhood and can therefore be considered a privileged type of learning that allows one to acquire biologically primary knowledge in an effortless and intrinsically motivated manner. Furthermore, it has been argued that haptics may support the acquisition of biologically secondary knowledge in educational settings as well (Paas and Sweller 2012). Within the context of multimedia learning, previous research has mainly focused on haptic learning materials specifically designed for instructional purposes, like touchable visualizations or three-dimensional abstract models, demonstrating positive effects on knowledge acquisition (Stull et al. 2018; Tang et al. 2019). According to object-based learning (OBL), haptic exploration of real authentic objects constitutes an additional class of instructional material that should similarly foster knowledge acquisition through processes of embodied cognition but has attracted far less empirical research to date (Chatterjee et al. 2015). To fill this research gap, the present study was set up to investigate whether haptic exploration of real objects, such as tools and artifacts, may serve as an additional channel for enhancing the learning experience and learning outcomes.

Firstly, based on findings from museum settings (Di Franco et al. 2015; Koran et al. 1984; Wilson et al. 2017), it was assumed that the participants would pay more attention to objects if they were given the opportunity for haptic exploration. Contrary to this assumption, we did not find evidence that participants inspected more objects, stayed longer in the first showroom, or reported higher situational interest if they were allowed to touch the exhibited objects. Several aspects may have contributed to the lack of effects of haptics on the participants' attention. In particular, the exhibition's topic of animal husbandry, animal welfare, and nutrition is currently highly debated in Germany. Independent of condition, this may have led both to the observed high rate of inspection of the exhibited objects and to the high scores in self-reported situational interest, while presenting further information via audio guides may have led to a homogenous duration of stay. Nevertheless, it should be kept in mind that both the choice of a current topic and the use of audio explanations reflect conditions that are typical of informal learning settings like exhibitions, thereby achieving a high level of external validity that was aimed at in the present study.

Secondly, referring to Hollins (2010) and Johnson et al. (1989), haptic exploration should serve as an additional input modality to process the learning material and to enrich its mental representation, also easing retrieval in and from the long-term memory. Directly after visiting the whole exhibition, the participants showed a high accuracy of remembered objects as long as they were presented to them in the first showroom either haptically, visually, or in a combination of both. Thus, there was a general advantage of the conditions in which the objects were present over the no-objects condition, indicating that vivid learning material, such as tools and artifacts, supports encoding and retrieval. More importantly, after 3 weeks, the participants who could use their visual and haptic senses during encoding remembered significantly more tools than participants who could only see or neither see nor touch the tools. In addition, there was no difference between the haptics and the vision-and-haptics condition, indicating that the participants who had a haptic experience were able to build a stronger mental representation of the exhibited tools. These results support the findings of Hutmacher and Kuhbandner (2018) that haptic experiences of objects lead to a durable long-term memory representation and also support the findings of Stull et al. (2018) that learning by enacting is stable over a period of several days.

In contrast, the knowledge test showed an advantage of the only-vision condition and the haptics-and-vision condition over the only-haptics condition directly after visiting the exhibition, while in the follow-up no differences between the experimental groups were found. Although the results should be interpreted with care due to the low internal consistency of the knowledge test, this indicates that in the present study haptic exploration did not help to relate additional learning content to the exhibited objects; if anything, the visual channel seems to have been more important in this case. This result stands in contrast to findings from research on finger tracing of printed visualizations and on the manipulation of molecular models, which have both reported positive effects of haptics on learning (Stull et al. 2018; Tang et al. 2019). The main differences to the present study are at least twofold, namely, the character of the learning material and its relationship to the content to be learned. While previous studies used abstract material that was specifically designed for certain instructional purposes and for which the haptic interaction was largely predetermined, the present study relied on authentic artifacts and tools which could be explored freely, as is the typical case in informal learning settings like museums and exhibitions. This unguided mode may have led the participants to apply familiar haptic exploratory routines which are typical for tools and artifacts and which helped them to build an enriched representation of the artifact itself, as evidenced by the memory advantage described above. But although research has demonstrated that such haptic exploratory routines may induce mental simulations of tool use procedures, in the context of the present study, this does not seem to be sufficient to help learners to integrate additional verbal information better than by purely visual inspection of the tools. Thus, contrary to the assumptions of OBL, the present findings indicate that unguided free haptic exploration of authentic objects does not necessarily lead to improved acquisition of additional knowledge about the objects.

In addition, the detrimental effects of the condition of haptic exploration without vision also question the assumption that object manipulation is a kind of biologically privileged process through which humans can acquire knowledge in an effortless way. Instead, the additional processing of haptic information may consume working memory resources. In fact, this may provide an explanation of why the participants in the only-haptics condition showed reduced performance in the knowledge test. Exploring objects in feeler boxes may have drawn the participants' attention to the material qualities of the artifacts, which may have in turn reduced resources for processing the information about objects presented via the audio guide.

Thirdly, based on findings that haptic exploration can lead to higher engagement during the learning process (Di Franco et al. 2015; Roberts et al. 2005; Wilson et al. 2017), we hypothesized that participants who could haptically explore the exhibits will be more motivated to deal with further information on the topic of the exhibition. Contrary to our expectations, we did not find evidence for this transfer of beneficial effects of haptic exploration to the second showroom regarding the duration of stay, the number of posters read, attention catch and hold measured by a situational interest scale, and knowledge acquisition. Independent of condition, most participants tended to inspect all of the posters presented in the second showroom and also reported a high level of situational interest. However, although the mean scores of the knowledge test were in the midrange, showing no floor or ceiling effects, no differences between the conditions were found. Taken together, we could not show that opportunities for haptic exploration support the subsequent acquisition of additional object-related knowledge or enhance the motivation to deal further with the topic.

Finally, based on the findings that affective responses can be evoked by the sensory feedback elicited by the act of touching (Oum et al. 2011; Peck and Shu 2009; Peck and Wiggins 2006; Skolnick 2013), we assumed that the participants who could touch objects in the first showroom will report more intensive affect than the participants who were not allowed to touch the objects. Considering the serious topic of animal welfare, it is not surprising that in all conditions the mood of the participants was not affected positively, but instead negatively by the exhibits. For the first showroom, this increase in negative mood was greater for the participants who could touch the objects than for those who were not allowed to touch them, supporting our hypotheses the haptic exploration will lead the participants to experience more intense affect because they were "touched" more deeply by the topic. After visiting the second showroom, we could not find any group differences in negative affect, but the negative affect remained at a higher level compared with before the visit, indicating that the differences in the first showroom were closely linked to the haptic experience but did not carry over to the second showroom.

Theoretical Implications

Taken together, the results of the present study have important implications both for multimedia learning theories, particularly for the CATLM, and for the role of embodied cognition for processes of knowledge acquisition.

Firstly, while CATLM considers narrations, sounds, texts, and pictures as instructional media, it has not yet considered three-dimensional material objects as a further type of instructional media. The present study showed that providing tools and artifacts that are relevant for the learning topic supports retention, regardless of whether they could be touched or not, indicating that they may serve an important role in multimedia learning environments. Besides real objects, similar effects have also been reported for material models such as chemical molecules (Smith 2016: Stull et al. 2018). Due to the growing possibilities of 3D printing, it is expected that three-dimensional material printouts will play an increasing role as an instructional medium in a broad variety of disciplines (e.g., Smith 2016; Stull et al. 2018). Hence, three-dimensional material objects, such as tools and artifacts, should be added to the list of instructional media in the CATLM.

Secondly, while previous research has focused on the auditory and visual senses, this study gives first indications that the haptic sense constitutes an additional channel to support and improve the learning process. This is not only the case for finger tracing of pictorial learning material (e.g., Agostinho et al. 2015) and manual interaction with three-dimensional models (Stull et al. 2018) but also for handling real objects. However, we only found the advantage of the (additional) haptic channel in the recall of the tools. Factual knowledge, which was reviewed in the knowledge test, was not improved by the haptic exploration, although previous research and theories on tool use and embodied cognition would suggest this. In our study, the linkage between the learning contents and the haptic exploration was perhaps not strong enough, questioning the assumption of OBL that free unguided haptic exploration of real objects is sufficient for increased acquisition of only weakly linked additional information. Instead, in the cited tracing literature (e.g., Agostinho et al. 2015, Du and Zhang 2019; Ginns et al., 2015; Macken and Ginns 2014; Tang et al. 2019), there was a predetermined, guided manual exploration, together with a clear, meaningful connection between the tracing and the learning material. This should also be the case for future studies investigating the role of touching and exploring three-dimensional objects, such as tools and artifacts, on different learning processes. The haptic experience should be directly linked to learning contents, for example, by trying out explained functions of a tool or by giving information on features that can only be haptically explored.

Thirdly, we found evidence that haptic exploration of real objects is effective at different levels of the CATLM: Through haptic exploration, memory processes were improved, and emotions were intensified. However, we did not find evidence that the haptic experience intensified the attention that learners pay to the learning material, helped the learners to relate additional learning content to the exhibited objects, or enhanced the motivation to stay engaged with the learning topic. One important conclusion that can be drawn from this finding is that the multimedia principles of temporal and spatial contiguity (Mayer and Fiorella 2014) also seem to hold for combinations of haptics with other sensory channels. As a consequence, redesigning the present exhibition into one showroom instead of two should increase spatio-temporal contiguity, fostering the development of an integrated representation of the information from the various sources. The findings also raise doubts on the assumption that the haptic exploration of authentic objects can be considered a learning mode that proceeds effortlessly without requiring additional cognitive resources. Therefore, on a more general level, the question arises whether the various well-established principles of multimedia learning apply as well for learning environments that include haptic exploration of authentic objects as part of the learning experience.

Limitations and Conclusions

There are several limitations of the present study that suggest directions for further research. Firstly, in our study, we decided to choose animal husbandry as a learning topic because the acquisition of knowledge of sustainable nutrition and animal welfare is of increasing importance. Nevertheless, the tools used are not neutral objects. They can trigger disgust, rejection, but also interest and curiosity due to the relevance of the topic. The findings show that being confronted with this topic and these tools led to an increase in the negative affect of the participants. Therefore, regarding the generalizability of the present findings, the effects of haptic exploration in the context of a more neutral topic will be necessary.

Secondly, in the context of the present study, it was not possible to collect observational data regarding the participants' touching and viewing behavior without the risk of substantial interference with the naturalistic character of the situation. Therefore, we purposefully decided to confine our research here to asking the participants about viewing and touching immediately after leaving the first showroom. In future studies, video protocols may supplement the participants' reports of their behavior in order to determine in more detail how the visual and/or haptic exploration of the objects took place.

Thirdly, due to the dropout rate in the follow-up questionnaire, our study might be underpowered regarding the follow-up, which means that small effects could not be detected by our analysis. The non-existence of effects should therefore not be overinterpreted. Further research with larger sample sizes is necessary to clarify the question of whether effects are actually not present or whether they could not be found in the present study only because of the data limitations.

Fourthly, given the restricted number of objects inspected in the present study, we also speculate that the beneficial effects of haptic exploration on attention and selection will be more pronounced under conditions of a larger set of real objects or a mixture of objects which can either be haptically explored or are not allowed to be touched.

Apart from these limitations, the present study showed that the haptic exploration of tools did have an impact on how we feel, and what we remember. This enhancement seems to be confined to the immediate haptic experience. Hence, the effects were not found while visiting the second showroom where the haptic experience was not available anymore. This suggests that the effect of haptic exploration is limited to the learning material and situation in which it takes place. Further research is needed to verify these results.

This study does provide theoretical implications for multimedia learning theories, especially on the integration of the haptic channel. But also on a practical level, the results of the present study do have implications for instructional uses of real tangible objects. If relevant information that is helpful for understanding the learning content is transported by the objects themselves, instructors may consider using real objects as authentic learning tools. Nevertheless, the results of the present study do not indicate that real objects may serve as motivators for further engagement with a learning topic.

The present findings are especially important for informal learning settings, like museums and exhibitions. Here, tools, artifacts, and other exhibited objects play a major role, and the preservation and composition in the showroom is a cost- and time-consuming task. The results of our study show that this is a worthwhile effort. In formal education, the findings are also of relevance. Imagine two lessons that differ only in whether or not tools were used for illustration. If a student can at least remember the name of the tools presented, this student has an advantage over a student who does not remember the tools because the former has a clue on what to research in order to catch up on the learning material. But, the results also point out that the uses of haptic exploration of authentic objects should be carefully orchestrated. In particular, although commonplace in informal learning settings, free unguided exploration accompanied by information that is not explicitly linked to the physical qualities of the objects does not seem to make the best out of haptics supported learning. Therefore, the present study should be considered a first step in how to implement haptic exploration of authentic objects in an instructional appropriate manner.

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