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Is children's naive knowledge consistent? A comparison of the concepts of sound and heat

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Abstract

The aim of this study was to shed some light on the organization of naive knowledge, and on the process of conceptual change in everyday physics, more specifically regarding the concepts of sound and heat. Eighty-three 8-year-old children were interviewed individually in order to see if they attributed the properties of objects (such as substantiality, weight, permanence, and trajectory) or the properties of physical processes (such as transmission by adjacency) to sound and heat.

The results indicated that material properties were attributed to these concepts in a hierarchical way. Permanence was abandoned first, then weight, and finally substantiality. The properties of matter were attributed somewhat more for heat than for sound. For substantiality, five different mental models constrained by different naive theories were inferred from the children's arguments. Naive knowledge about sound and heat thus appears to be organized in a relatively coherent way and conceptual change from one naive theory to the next seems to be slow and gradual.

1. Introduction

Research on cognitive development has long favored the study of the structure of mental operations over the study of the structure of knowledge. This holds true not only for Piaget's theory, but also for most developmental models based on

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information processing. In current developmental psychology, there is a growing interest in conceptual change and the domain specificity of that change. The research on this topic concerns knowledge qualified as "intuitive", or "naïve" that children build from phenomena they observe in their everyday life, before receiving any systematic instruction in the corresponding scientific theories (for a review, see Wellman & Gelman, 1992, 1997).

Many points are debated in this field of research. First of all, the assumption of naive knowledge structuring is not unanimously accepted. If for some authors this knowledge is organized, for others it is rather inconsistent. The latter point of view was defended in particular by diSessa (1993), who studied the naive ideas that physics students have about certain physical phenomena. According to diSessa, the intuitive explanations given by these novice students are frequently "phenomenological primitives (p-prims)". Their explanations are called "primitives" because they appear obvious and self-evident, and constitute explanatorily primitive descriptions of events. They are called "phenomenological" because they are rooted in the experience subjects gain from their interactions with the physical world (e.g. the experience of resisting a force). Each primitive is related to the context experienced by the subject, but they are not interconnected into a coherent structure: "As a system, p-prims are diverse and loosely coupled. There is no strict hierarchy, no global level of importance, nor any logical chain from primary to derived p-prims" (diSessa, 1996: p. 715). P-prims are "knowledge in pieces". More recently, diSessa introduced new levels of organization for naive knowledge, such as mental models, narratives, nominal facts, or committed facts, more loosely organized than concepts, beliefs, or naive theories. However, the role of these larger levels of organization seems to be limited in folk physics, and to develop with instruction instead: "committed facts are perhaps the closest thing to 'naive theories' that I believe exist. But even these do not have the range and rich substructure that typify scientific theories. Furthermore, they are rare and probably provoked more frequently by instruction than they are spontaneous … It would not be a bad approximation to say that folk physics is the rather large diverse and mildly organized collection of fairly simple phenomenological ideas, which are p-prims" (diSessa, 1996: p. 719).

However authors who, on the contrary, see naive knowledge as being organized in nature diverge on the type and origin of this organization. The divergences seem to hinge upon what answer is given to the following question: does the formation of new knowledge imply former knowledge? If the answer to this question is yes, one must admit that to form new knowledge at time t, a subject must have a previous knowledge structure formed at time $t-1$. It follows from this that, in turn, knowledge formed at time $t-1$ implies structured knowledge at time $t-2$, and so on. This position logically results in agreeing that some form of knowledge organization, or at least some constraints on the acquisition of knowledge, are already present at birth, when development begins.

Those who, instead, compare conceptual development to the passage from the state of a novice to that of an expert do not share this point of view. Chess, for example, is an activity about which one has few reasons to believe that there has been a selection process, at the phylogenetic level, of innate predispositions to learn the rules of the game. Because humans seem to be able to go from a state of complete ignorance to a state of expertise in this activity, why couldn't the same hold true of more fundamental domains of knowledge, such as physics or knowledge of the mind?

The greatest divergence between these various approaches to naive knowledge thus seems to be about what is considered to be primitive in knowledge acquisition: some elementary rules, phenomenological ideas, and schemes, or some general presuppositions, constraints, and theories? There are also intermediate positions. Howe (1998), for example, following Piaget, sees primitives as actions, but also admits, following Vygotski, that in some cases, causal mechanisms are accessed directly through language and socio-cultural influences, and in these cases, play the role granted to naive theories in other approaches.

A larger number of researchers agree upon the existence of an initial core of innate foundational principles which predispose infants and very young children to detect and use certain basic regularities that characterize their physical and social environment (e.g. Carey, 1991; Carey & Spelke, 1994; Spelke, Breinlinger, Macomber, & Jacobson, 1992; Vosniadou, 1994; Vosniadou & Brewer, 1992; Wellman, 1990). Note that there is some ambiguity concerning the nature of this initial "knowledge". It seems to be more like precursors of later knowledge than like knowledge itself. This is at least what the terms employed to refer it suggest: preconceptions, presuppositions, beliefs, tacit knowledge, foundational principles. However, there is a clear consensus over the idea that these core foundational principles or presuppositions constrain the acquisition of later knowledge, and consequently delimit specific domains of knowledge.

There is a debate concerning the number of core principles and the number of domains that must be distinguished, although authors agree on at least two main domains: matter and mind (Wellman & Gelman, 1997). The basis of the specificity of these domains is the specificity of the causal principles that govern them. The behavior of objects is explained in terms of the solidity, permanence, contact, transmission of forces, etc. (Spelke, 1991), whereas the behavior of people is understood in terms of the principles of intentionality, desire, and belief (Wellman, 1990). These explanatory principles constrain the knowledge structure of each domain and thus leads to its specificity. They also outline ontological categories, i.e., categories of entities that differ in essence. Mental states and objects have fundamentally different attributes and are therefore allocated to fundamentally different ontological categories. According to Keil (1989), the bases of these ontological distinctions are innate. As mentioned above, there is some disagreement about the number of ontological categories or specific domains that should be distinguished. Is there a naive biology in addition to naïve physics and naive psychology? Is knowledge of numbers domain-specific?

Even those who agree on the existence of very early core foundational principles are not unanimous on all points, in particular regarding the nature of the process of conceptual change. They diverge for example on the extent of the revisions these principles can undergo with experience. According to some authors, core principles are modules. Fodor (1983) popularized the idea of modules to describe the functioning of peripheral systems. Contrary to what Fodor thought, the assumption of the above authors is that modularity is not specific to peripheral cognitive systems, but can be extended to the central system, and also to concept formation. This approach to knowledge structuring was defended by Spelke (1991) in regards to the foundational principles of naive physics, and by Baron-Cohen (1995) and Leslie (1994) in regards to the foundational principles of naive psychology. For the proponents of modules, conceptual change is an enrichment of the initial structure, whose core principles, being the product of phylogenetic evolution, are not revisable.

This modular approach to concept formation is not shared by authors who compare core principles to theories (see for example Carey, 1985, 1991; Vosniadou, 1994; Vosniadou & Brewer, 1992; Wellman, 1990). Like the proponents of modularity, these authors contend that primitives are principles, but they consider these principles to be revisable with experience. Accordingly, naive knowledge, though quite different from scientific knowledge, shares with it the characteristic of being organized in the form of coherent explanatory systems which are generative and support prediction making. If the predictions made fail, it leads, with more or less resistance, to the revision of the theory, including its foundational principles. In this sense, naive theories are assumed to play a role with respect to everyday knowledge that is similar to the role played by scientific theories with respect to scientific knowledge. For the proponents of theories, conceptual change is slow, gradual, and relies on the revision of these theories, including their foundational principles.

A more radical form of conceptual change is envisaged by authors for whom primitives of knowledge acquisition are constraints imposed by ontological categories. According to Chi, Slotta and Leeuw (1994), misconceptions are attributed to a mismatch between the ontological categories to which subjects assign concepts and the ontological categories to which concepts usually belong. Conceptual change is then considered as the reassignment of a concept to a new category, and is therefore assumed to trigger a rather sudden shift: "...once a concept has been re-represented on a different ontological tree, the concept immediately inherits the attributes of that tree. This immediate inheritance can provide the 'aha' phenomenon" (Chi, 1997: p. 230). In physics, for example, subjects have trouble understanding concepts such as electrical current, heat, and light because they assign these entities to the category of matter when they belong to the ontological category of processes, or more precisely, according to Chi et al., to the subcategory labeled "constraint-based interaction". The attributes of the constraint-based interaction subcategory include: no beginning or end, no progression, non-causal, uniform in magnitude, simultaneous, ongoing, etc.

2. The present study

The present study was aimed at clarifying some of the points under debate on the issue of conceptual change. The first point concerns the degree to which naive knowledge is organized. Is knowledge made of unrelated pieces, as suggested by diSessa, or is there a certain coherence among these pieces, as suggested by both the proponents of naive theories and the advocates of domain-specific modules? The second point concerns the nature of conceptual change. Is there a process that reassigns a concept to a new ontological category? If so, is the change a relatively abrupt process in which a concept can have the attributes of one or the other of its successive ontological categories but not of both at the same time, or is it a process of revision with experience of the naive theory underlying that concept? In the latter case, one can assume that the change will be a slow, gradual process in the course of which the attributes of old and new ontological categories coexist for quite some time.

The domain retained for this study was physics, and more specifically, the concepts of sound and heat. In a previous study, the two important points mentioned above were explored for the concept of sound (Mazens & Lautrey, 2000a,b, in press). The first goal of the present study was to find out whether the results obtained for sound could be replicated. The second goal was to determine whether the structure of knowledge found for sound is specific to that concept or can be generalized to the concept of heat, which belongs to the same domain and, in principle, to the same ontological process category. Let us begin by summarizing the results of this earlier study on sound.

Naive conceptions of sound have not been studied extensively. According to Piaget (1971), 4–5-year-old children think that nothing passes between an emitting object and a person's ears. For 6-year-old children, sounds remain in objects even when we do not hear them, they go to people's ears and nowhere else, and then come back to their source. Starting at the age of seven, children conceive of sound as moving in straight lines in all directions. Finally, at the age of 11, sound is conceived of as a kind of "tapping" that resonates and spreads with air as the medium (it can also be conceived of as air itself). For older subjects, studies conducted on novices and experts in physics have shown that sound can be conceived of as a substance (Linder, 1993; Linder & Erickson, 1989; Maurines, 1992).

In our previous research (Mazens & Lautrey, 2000a,b, in press), we studied the coherence and nature of conceptual changes in naive knowledge about sound in children ages 6–10. In order to find out if knowledge is organized into ontological categories, naive theories, or "pieces", we tried to determine whether children assigned to sound some of the properties of matter or of processes. The object properties studied were substantiality, weight, and permanence. For the process properties, we looked at whether children had an idea about the vibratory process responsible for the production and transmission of sounds, and if they thought that a medium was necessary for transmission.

For substantiality, for example, we asked children to explain why it is possible to hear a sound through a solid. Their responses suggested the presence of five mental models, based on three successive theories. The first theory (Theory 1) seems to ascribe sound the properties of matter, in particular substantiality. The initial mental model (Model 1) is a representation in which sound cannot pass through other solids. In order to explain observations which at first glance contradict this initial model, such as the fact that sounds can sometimes be heard through solids, children seem to develop what Vosniadou (1994) calls "synthetic mental models", or mental models that allow them to reconcile the constraints of the assumption of substantiality (a solid cannot cross another solid) and the empirical observation that sound can pass through some solids. To explain that an entity that is a substance can nevertheless pass through a solid, the first synthetic mental model (Model 2) is based on the presence of holes. The second synthetic mental model (Model 3) compares "the force" or the hardness of a sound to that of solids. Sound can pass through a solid if it is harder ("stronger") than the solid. The next mental model (Model 4) does not seem to be constrained by the theory of the materiality of sound. Children abandoned the idea that sound is a substance but without being able to explain the process of transmission. This fourth mental model qualifies sound as transparent, invisible, and different in nature from objects or human beings. The underlying theory (Theory 2) seems to be that some entities like ghosts, sounds, and air keep the essence of matter but none of its usual properties. The last mental model (Model 5) seems to rely on the use of terms specific to the transmission of sound, such as vibrating and resonating. This mental model seems to be the first one that is constrained by presuppositions coming from a framework theory (Theory 3) of processes (the core idea being that of transmission by adjacency) but appears to no longer be based on explicit knowledge of processes. With development, the idea of the presence of holes was found to decrease in favor of arguments about the immaterial nature of sounds and the processes of resonance and vibration.

This earlier study also showed that the properties of weight and permanence were not attributed much to sound. Preschool children more often attributed these properties than did older children. The coherence between properties was studied by considering the attribution patterns for the various properties. The three properties of matter (substantiality, weight, and permanence) were attributed hierarchically rather than in a synchronic way. If children attributed the properties of permanence and weight to sound, then they also attributed the property of substantiality. With development, permanence and weight were the first properties to be abandoned. Belief in substantiality persisted the longest. From these results, we concluded that children's naive knowledge of sounds is organized with some degree of coherence, and that conceptual change is slow and gradual.

Given these results, we wondered if knowledge could be organized in a similar way for another concept that shares some characteristics with sound. Heat is also a phenomenon belonging to the domain of physics. It is a process which involves transmission by adjacency without any displacement of matter. The age of eight was chosen for the present study because we had observed notable differences between children's representations of sound at this age in our previous research.

Studies on naive representations of heat are more numerous than those on naive representations of sound. Because our own study was not aimed at studying naive representations of heat per se, but rather at comparing two kinds of naive representations from the point of view of conceptual change, only some of the studies on heat will be mentioned here. Erickson (1985) and Tiberghien (1985) pointed out that in our everyday language, we use the word heat in a different way than it is employed in science. Heat is described as if it could be stored, transferred, and displaced so it may be conceptualized as a substance. Many studies have been conducted about the difference subjects make between heat and temperature (Kesidou & Duit, 1993; Stavy & Berkovitz, 1980; Strauss & Stavy, 1982) and about material's isolation or conduction of materials (Howe, 1998; Lewis & Linn, 1994).

As already mentioned, the second purpose of the present study was to examine the consistency of children's naive representations of the concepts of heat and sound. We wanted to determine whether knowledge is organized in the same way for these two concepts. Is children's naive knowledge of heat and sound fragmented and loosely organized, as assumed by diSessa, or is it structured around core principles, either in terms of ontological categories (as assumed by Keil and Chi et al.) or in terms of naive theories (as assumed by Carey and Vosniadou)?

If naive knowledge about sound and heat is organized into ontological categories, children should first assign sound and heat concepts to the ontological category of matter before attributing them to the ontological category of processes. According to this conception, sound and heat possess all the attributes of the category to which they are assigned. This means that if children assign sound and heat to the ontological category of matter, then they should assign all the attributes of matter to sound and heat. Similarly, if they assign sound and heat to the ontological category of processes, then they should assign them all the attributes of processes. The object properties considered in this study are substantiality, weight, and permanence. For the process properties, we looked at whether children have an idea of the transmission by adjacency. We also wanted to find out whether children represent the trajectories of sound and heat as following a sequential or simultaneous path, and as going only to people or going everywhere.

If knowledge is organized into naive theories, then this organization should be coherent, but its coherence may be less noticeable at first sight and may be found in the explanatory principles (presuppositions) underlying children's responses. At some developmental stages it should be possible to observe the coexistence of some attributes of the ontological category of matter and some attributes of the ontological category of processes.

Finally, if their knowledge is incoherent, children should have superficial, fragmented responses about sound and heat. These responses should not be constrained by an underlying structure, and the knowledge should become more coherent only with instruction.

We also studied the synchrony of the representations of sound and heat. Do children attribute some presuppositions of matter to heat as well as to sound? Do they have an idea about the transmission by adjacency? Does the same framework theory constrain children's representations of sound and heat at the same moment? To answer these questions, we focused on within individual consistency. In other words, we looked at whether the same child gave similar or different explanations, from a structural point of view, for these two physical phenomena.

3. Method

3.1. Participants

The participants were 83 second-grade children (mean age: 7 years 8 months, range 6; 2–9) who were attending an elementary school in Paris. They came from middle-class backgrounds. Approximately half of the children were girls and half were boys.

3.2. Materials

3.2.1. Situation 1: substantiality

Substantiality refers to the fact that sound and heat are assumed to be made of matter and thus cannot pass through solids. For this property, there was a prediction phase in which the children had to predict the result of an experiment that was not actually done, and an observation phase in which the experiment was really conducted. In each phase (prediction and observation), the same question was asked about three different materials. This design was used solely for the study of substantiality. For the other properties, only the prediction phase with one material was retained.

3.2.1.1 Materials for heat. For the prediction phase, there were three items. In item 1 (metal box), the experimenter showed the children a small glass bottle containing very hot water and made them feel the heat without touching the bottle. The experimenter enclosed this bottle in a metal box and asked the children to predict whether they could feel the heat by putting their hands near the box. In Item 2 (cardboard box), the same procedure was used for item 1 but the box was a cardboard box. In item 3 (wall), the experimenter asked the children if it was possible to feel heat through walls. The same three items were used for the observation phase. For item 4 (metal box), when the children answered that it was not possible to feel the heat in the metal on item 1, they were asked to put their hands near the box so they could actually feel the heat through the box. They were then asked why heat could be felt through the box. For item 5 (cardboard box), the same procedure was used as in item 4 but the box was made of cardboard. For item 6 (wall), when the children answered that it was not possible to feel heat through walls on item 3, the experimenter asked them to explain why, if they have neighbors downstairs in their apartment building who heat a lot, the heat will be transmitted up to them. For each question, children were asked to justify their answer.

3.2.1.2 Materials for sound. The three items for the prediction phase were as follows. On item 1 (metal box), the experimenter asked the children to listen to the ticking of a clock, enclosed the clock in a metal box, and asked them to predict if they could hear the noise if they put the box near their ears. On item 2 (cardboard box), the same procedure was used as on item 1 but with a cardboard box. On item 3 (wall), the experimenter asked the children if it is possible to hear noise through walls. For the observation phase, the items were as follows. For item 4 (metal box), when the children answered that it was not possible to hear the clock in the iron box on item 1, the experimenter placed the box near their ears so they could realize that they could in fact hear the ticking through the box. They were asked to explain this observation. For item 5 (cardboard box), the same procedure was used as in item 4 but with the cardboard box. For item 6 (wall), when the children answered that it was not possible to hear noise through walls on item 3, the experimenter told them that they had already heard noise through walls at school or at home. They were asked to explain this observation. For each question, children were asked to justify their answer.

3.2.2. Situation 2: weight

3.2.2.1 Materials for heat. The experimenter showed the children a spoon that had been heated by plunging it into hot water, the experimenter led them to notice that it was hot, and then put it on the table. Next, the experimenter asked the following question: "A child told me that the spoon becomes a little lighter when it cools. Do you think he is right or wrong? Why?"

3.2.2.2 Materials for sound. The experimenter made a noise with two sticks and then asked the children the following question: "A child told me that at the moment the two sticks hit each other, they become a little lighter. Do you think he is right or wrong? Why?"

3.2.3. Situation 3: permanence

3.2.3.1 Materials for heat. The experimenter turned on a toaster so the children could feel the heat spreading through the room and then turned it off. Next the experimenter presented a drawing that depicted the room where they were, and asked the child to draw where the heat went in the room and especially how far. If the child answered that the heat went out of the room, the experimenter showed other drawings depicting the school, street, city, etc., and the child was asked to continue drawing where the heat went. Finally, the experimenter asked whether heat goes on forever, stops and stays where it is, or disappears and ceases to exist.

3.2.3.2 Materials for sound. Two sticks were hit together to make a noise. When the noise could no longer be heard, the experimenter presented a drawing depicting the room where they were and asked the child to draw where sound went in the room and especially how far. If the child answered that the sound went out of the room, the experimenter showed other drawings depicting the school, street, city, etc., and asked the child to continue drawing where the sound went. Finally, the child was asked whether sound goes forever, stops and stays where it is, or disappears and ceases to exist.

3.2.4. Situation 4: trajectory

3.2.4.1 Materials for heat. The experimenter turned a toaster on, so the child could feel the heat spreading through the room, turned the toaster off, and showed a drawing of the toaster and three people. The child was asked to draw where the heat went, and what path it took.

3.2.4.2 Materials for sound. Two sticks were hit together to make a noise. The experimenter then presented a drawing showing the sticks and some people, and asked the child to indicate where the noise went, and which path it took.

3.3. Procedure

The children were tested individually, using a semi-structured interview. They had to predict the experiment's results, justify their responses, explain contradictions between their predictions and observations, judge the productions of other children, and add to the drawings. Their responses were recorded using a tape recorder, and then transcribed.

3.3.1. Order of presentation of concepts

The children were interviewed twice—once about sound and once about heat—with at least 1 week between the two interviews. The order of the two concepts was counterbalanced (43 participants had the heat–sound order and 40 had the sound–heat order). The interviews lasted approximately 20 min each.

3.3.2. Order of presentation of situations

The situations were presented to all children in the following order: substantiality, weight, permanence, and trajectory. This order was selected to provide a logical progression of questions. For example, children had to think about transmission before thinking about permanence or trajectory.

3.3.3. Order of presentation of phases and materials

In the substantiality situation, which was the only one to comprise two phases and three materials, the prediction phase was run first for the three items (metal box, cardboard box and wall) and then the observation phase was run for those same three items. Within each phase, the order of the three items was counterbalanced across subjects.

3.4. Scoring

Children's arguments were categorized according to whether they seemed to attribute a given property to sound or heat. A child's answer to a given question was classified in one category only. The slight variations across the tables presenting the observed frequencies of subjects are due to the few cases in which a response was lacking or impossible to code in our categories.

Inter-rater reliability was assessed on a random sample of 40 interviews (20 about sound and 20 about heat). Agreement between the two independent judges was high: 94.75% of agreement with a Kappa coefficient of 0.93. The different scoring categories will be presented in the results section.

4. Results

The data analysis concerned two forms of consistency: consistency between concepts and consistency between properties within each concept. First, for each property considered (substantiality, weight, permanence, trajectory), we studied the consistency between the arguments given for the two concepts (sound and heat). We looked at whether the arguments were the same and if they were attributed at the same frequency for the two concepts (in this case, McNemar's χ^2 for dependent samples was always computed). Then we determined whether there was a significant relationship between the attribution of a property to sound and heat (in this case, Pearson's χ^2 for independent samples was computed, along with the Kappa coefficient in order to quantify the intensity of this relationship). The second form of consistency examined was between properties within each of the two concepts. The question asked was: did the patterns of attribution of the various properties correspond to what could be expected in case of transfer of the concept from the matter category to the process category, or did the patterns correspond to what could be expected in case of a gradual revision of children's naive theories of sound and heat?

4.1. Interview order

There was no significant effect, at the 0.05 level, of the order of the interviews (heat–sound or sound–heat). Therefore, order was ignored for purposes of analysis.

4.2. Substantiality

4.2.1. Scoring categories

Four kinds of arguments were given by the children to justify that we can feel heat or hear sound.

(1) Heat or sound is enclosed or there are holes: the children explained that we cannot feel heat or hear sound because they are enclosed, or that we can feel heat or hear sound because they go through holes. These holes could be visible (space between lid and box, space under a door, cracks, keyhole) or not visible.

Examples for heat:

> Rém.: "No because heat can't go through walls, concrete, because it [heat] is small and it is like dust."
> Dan.: "No we can't but when there is a door, we can because there are holes."
> Lio.: "It passes like that, through here, because there is a very small space."

Example for sound:

> Mar.: "There is a door in a wall and we can hear. The noise goes through the lock and under the door."

(2) Relative strength of heat and sound and of materials: the children explained that we can or cannot feel heat or hear sound depending on the properties of the material, i.e. its hardness or strength.

Examples for heat:

Jes.: "No, because it's made of metal and it's a lot harder than cardboard, so the smoke can't leave."
Mar.: "Yes, maybe the heat is stronger than the box. It can sometimes pass."
Mic.: "Yes because cardboard is softer. The smoke can go outside here because the box is soft and everything can go out."

Example for sound:

Mic.: "Either it fights to go out of the box, which means that it moves quickly toward the box and it tries to get out. Or we don't feel it, it doesn't fight and it can't get out. It is as if I kicked the wall down and I went by force. May be it has kicked the metal down, it got through by force."

(3) Heat and sound as immaterial: The children referred to the immaterialness of heat and sound. They compared it to a ghost or mentioned that it was invisible or of a different nature than their own bodies.
Examples for heat:

Lor.: "Yes, because it is smoke and the smoke can pass between something, like a ghost."
Nas.: "Because it is transparent, the smoke, so it can go up, up."

Example for sound:

Max.: "Noise, it's not something like a sheet of paper that can cross like that so... it's something else."

(4) Preliminary representation of process: for this category of response, arguments differed for sound and heat but seemed in both cases to imply some preliminary attributes of the process category, namely, the idea of transmission by adjacency. For heat, none of the children explained the transmission in a scientific way. On the other hand, some children explained transmission by adjacency. For sound, the children used specific terms such as to resonate, or to vibrate, although they did not seem to know the exact scientific explanation.
Example for heat:

Jul.: "Since it's hot, the little bottle will make steam on the cardboard box and the cardboard box will get hot."

Example for sound:

Jul.: "If we speak too loud, it resonates in the walls and we hear. It goes on the walls, then it goes inside and it goes through the other side making a vibration."

4.2.2. Consistence between concepts

There was no significant effect, at the 0.05 level, of the order in which the materials were presented (metal box, cardboard box, and wall), for sound or for heat. With all factors pooled, the arguments used by these 8-year-old children to explain that sound and heat can be perceived through solids usually referred to the existence of holes or to the relative strength of the material through which it passed. Responses that did not imply substantiality (immaterial nature of sound and step by step processes) were still infrequent at this age. More precisely, the mean frequencies of the arguments given for sound are 0.53, 0.34, and 0.13 for "holes", "strength", and "immaterial" + "step by step", respectively. For heat , they were 0.54, 0.37, and 0.09, respectively. Variations between sound and heat in the frequencies of these various different types of arguments were thus very small. Variations across phases (prediction or observation) and materials (metal box, cardboard box, or wall) were not great either. At the descriptive level, arguments that did not imply substantiality ("immaterial" and "step by step") tended to be a little more frequent in the observation phase than in the prediction phase. For all materials pooled, the mean number of children (over 80) who gave these kinds of explanations was 8 for sound and 4 for heat on the prediction phase, and 13 for sound and 10 for heat on the observation phase.

A log-linear analysis was performed with concept (sound, heat), phase (prediction, observation), and material (metal box, cardboard box, wall) as design variables, and type of argument ("holes", others) as dependent variable ("strength", "immaterial", and "step by step" were grouped into one category and opposed to the "holes" category in order to keep the expected frequencies per cell at an acceptable size). None of the associations between the design variables and the response variable, at any level, were significant.

Given the lack of significant effects of the design variables, only one table (Table 1) is given here as an example (Tables A1–A5, corresponding to the five other conditions of situation 1, are given in Appendix A). Table 1 cross-tabulates the various arguments given by the children for heat and sound in the "wall" item of the observation phase. This item was chosen because it is the item for which "immaterial" and "step-by-step" arguments, which were still rare at this age, were the most frequent for both concepts.

Table 1
Substantiality, observation for the wall item: number of arguments of each type for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	30	6	1	0	37
Strength	14	6	4	2	26
Immaterial	1	1	3	0	5
Process	6	3	0	0	9
Total	51	16	8	2	77

The consistency of the arguments given for the two concepts on each of the six items (2 phases × 3 materials) was evaluated by computing Pearson's χ^2 and kappa coefficients (K) for each of the six corresponding tables (Tables A1–A5 and Table 1). For this analysis, the argument variable was dichotomized as in the log-linear analysis, for the same reason. For the prediction phase, the values of the consistency indexes were $\chi^2(1) = 5$, $p < 0.05$, $K = 0.22$; $\chi^2(1) = 3.92$, $p < 0.05$, $K = 0.19$; and $\chi^2(1) = 2.9$, $p < 0.10$, $K = 0.13$, for the metal box, cardboard box, and wall, respectively. For the observation phase, the indexes were $\chi^2(1) = 5.83$, $p < 0.05$, $K = 0.36$; $\chi^2(1) = 5.83$, $p < 0.05$, $K = 0.38$; and $\chi^2(1) = 5.83$, $p < 0.05$, $K = 0.18$. The consistency of the explanations given for the two concepts in the same situation (same phase and same material) was thus present in both phases but stronger on the observation phase. So, although the argument frequencies were rather stable across concepts, phases, and materials, within-subject argument consistency between the two concepts was not very high. These inconsistencies occurred mainly between the two most frequent arguments, holes and strength. In these 8-year-olds, the two kinds of explanation, both of which reconcile the presupposition of substantiality with the observation that sound (or heat) goes through solids, seem to be both available and many children are able to shift from one to the other when they pass from one concept to the next.

4.3. Weight

4.3.1. Scoring categories

The children's responses were assigned to one of two response categories depending on whether they assigned the property of weight to sound or heat.

Example for heat:Arguments given to explain that the spoon got lighter when it cooled:

> Ama.: "He is right. The heat, it's a little heavier, but it can't be seen."

Arguments given to explain that the spoon did not get lighter when it cooled:

> Jes.: "He's wrong because a spoon, it always stays the same even if it's cold or hot because it's only vapor that leaves."
> Tri.: "If it's hot, it has nothing to do with whether it is heavy or light."

Examples for sound:Arguments given to explain that the wooden sticks got lighter:

> Ang.: "He's right, when you hit a little on it, sound goes away, and from the fact that it goes away, it makes the wood lighter."

To explain that the sticks did not get lighter, the children said that the sticks retained their size and their weight so they stayed the same:

Table 2
Weight: number of children who attributed weight to sound and to heat

Sound	Heat		Total
	Weight	No weight	
Weight	14	8	22
No weight	20	31	51
Total	34	39	73

> Cam.: “When we make noise, it’s the stick that hits, it’s not as if it removes something if there are stones stuck to a stick. If it hits and it removes the stones, it will be lighter, but here, it’s not lighter.”

4.3.2. Consistency

As can be seen in Table 2, weight was more frequently attributed to heat (46%) than to sound (30%): ($\chi^2(1) = 5.14$, $p < 0.05$). The relationship between the two concepts, with regard to the attribution of weight, was significant but weak ($\chi^2(1) = 3.68$, $p = 0.05$, $K = 0.21$).

4.4. Permanence

4.4.1. Scoring categories

When the children answered that heat or sound would always exist, it was inferred that they attributed permanence to the concept. When they answered that heat or sound disappeared, that they no longer existed, it was inferred that they did not attribute permanence to the concept.

Examples for heat:The children answered that heat could always exist, could be transformed, or could disappear.

Heat could come back in the toaster:

> Lio.: “If we turn off the toaster, all the heat comes back into the toaster.”

Heat could be transformed into cold, wind, clouds, or smoke:

> Flo.: “It goes into the clouds and that’s what makes the clouds. It’s steam. If the clouds stay, it always exists.”

Some children thought that it disappeared, because it cooled.

> Val.: “As it goes more and more toward here where it’s not hot, it cools and then it disappears.”

To explain that heat disappeared, the children said that it evaporated, disappeared in vapor, disappeared in smoke, got smaller, or went out, or that the wind carried it away.

Cle.: "When it has all been deposited along its path so that there's no more, it stops."

Examples for sound:Different kinds of explanations were observed.

Riz.: "Then, it comes back to its place."
Sop.: "It decreases, it decreases and then, there's no more."
Ang.: "Sound spreads everywhere after that. It goes farther and farther. The more it makes less sound, the more it disappears."
Jul.: "It stops when the vibrations are stopped."

4.4.2. Consistency

Permanence was hardly ever attributed to sound or to heat by these 8-year-old children. However, it was ascribed slightly more often to heat (23%) than to sound (13%) ($\chi^2(1) = 3.56$, $p < 0.10$). The relationship between the arguments given for heat and sound was significant ($\chi^2(1) = 7.20$, $p < 0.01$; $K = 0.28$). (See Table 3)

4.5. Trajectory

4.5.1. Scoring categories

Two things in particular were analyzed in the children's drawings: (1) whether they depicted sound (or heat) as going only to people or also going elsewhere, and (2) whether they depicted sound (or heat) as having a sequential trajectory (going successively from one place to another, as objects do) or a simultaneous trajectory (going simultaneously to different places, as processes do). Four examples of drawings are given in Fig. 1.

4.5.2. Consistency

Regarding sequential or simultaneous trajectories, contrary to what was observed in the preceding tables, the attribution of object properties, here a sequential trajectory, was more frequent for sound (48%) than for heat (38%) ($\chi^2(1) = 5.33$, $p < 0.05$). The relationship between the drawings produced for the two concepts was very strong ($\chi^2(1) = 43.29$, $p < 0.0001$, $K = 0.71$). (See Table 4)

Table 3
Permanence: number of subjects who attributed permanence to sound and to heat

Sound	Heat		Total
	Permanence	No permanence	
Permanence	6	5	11
No permanence	13	59	72
Total	19	64	83

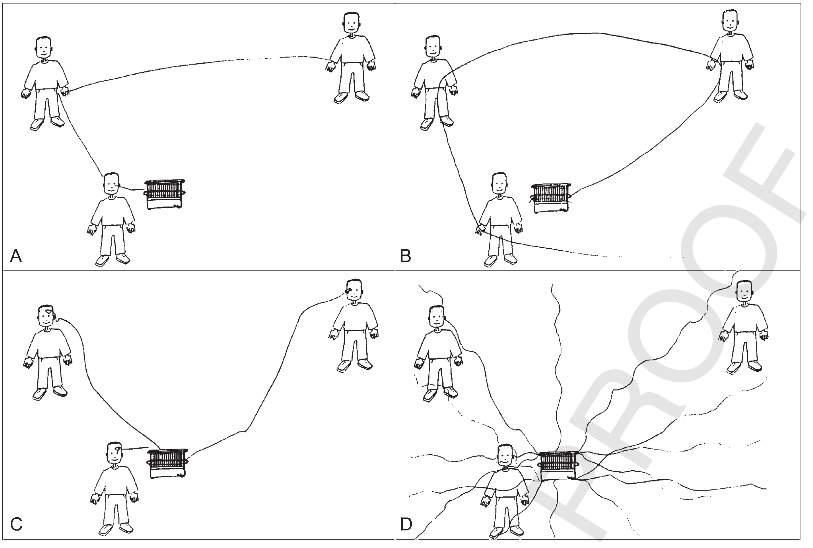

Fig. 1. Four examples of drawings for heat: (A) sequential trajectory only to people; (B) sequential trajectory everywhere; (C) simultaneous trajectory only to people; (D) simultaneous trajectory everywhere.

Table 4
Trajectory: Number of drawings in each category for sound and heat

Sound	Heat		Total
	Sequential	Simultaneous	
Sequential	30	10	40
Simultaneous	2	41	43
Total	32	51	83

Regarding trajectories that went only to people or somewhere else, the same relations were observed (see Table 5). The drawings in which the phenomenon was propagated only towards people were also more frequent for sound (45%) than for

Table 5
Trajectory: number of drawings in each category for sound and heat

Sound	Heat		Total
	Only people	Not only people	
Only people	20	17	37
Not only people	5	41	46
Total	25	58	83

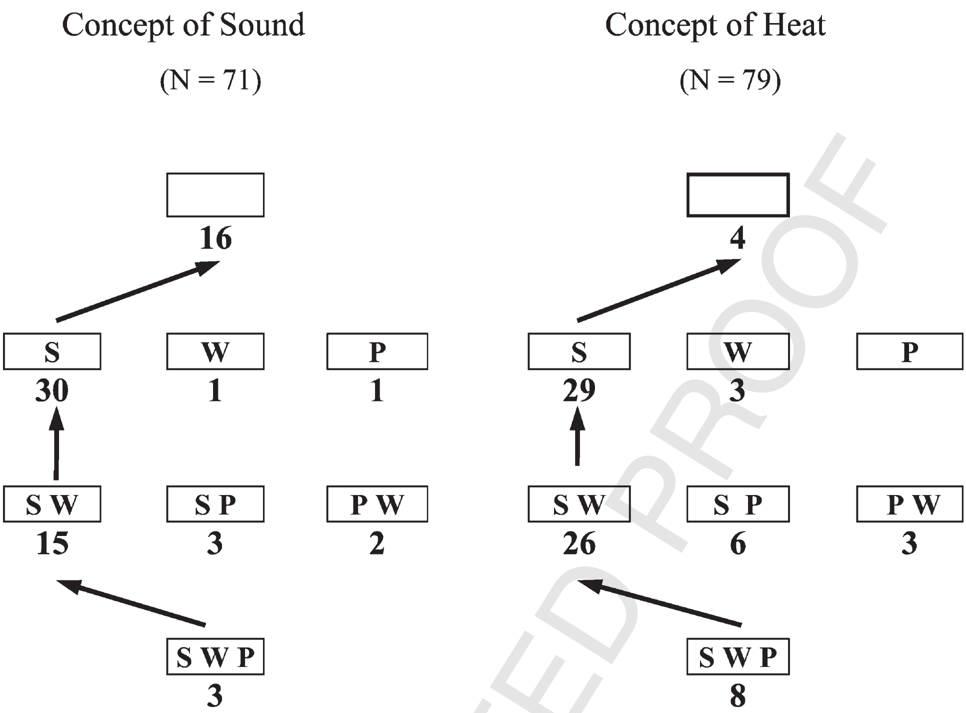

Fig. 2. Patterns of attribution of substantiality (S), weight (W) and permanence (P). Under each pattern box is the number of children who obtained that pattern. Among all possible pathways going from the level corresponding to the attribution of the three properties (SWP, bottom of the graph) to the level corresponding to the attribution of none of these properties (empty box, top of the graph), only the pathway corresponding to the largest number is depicted by arrows.

heat (30%) ($\chi^2(1) = 6.54$, $p < 0.05$). The relationship between the drawings produced for the two concepts was also rather strong here ($\chi^2(1) = 18.17$, $p < 0.0001$, $K = 0.45$).

4.5.2.1 Consistency between properties. The various patterns of attribution of the main properties of matter, i.e. substantiality (S), weight (W), and permanence (P), to sound and heat are represented, with their frequencies, in Fig. 2. Substantiality was inferred from the explanations given in the observation phase of the wall situation (see Table 1).[1] The substantiality category included the following explanations: presence of holes, and the relative strength of sound (or heat) and

[1] The results concerning between properties consistency were approximately the same when any other of the six items used to study substantiality was chosen (remember that neither of the design variables, phase or material, had a significant effect in the log-linear analysis). The wall situation of the observation phase was chosen because there were slightly more children giving immaterial and step by step arguments in this situation and thus the dispersion of arguments was slightly better for both sound and heat.

solids. The no-substantiality category included the following explanations: immaterial and preliminary representation of process.

For sound (left graph in Fig. 2), for example, three subjects in this sample of 8-year-old children obtained the pattern SWP, which means that they attributed substantiality, weight, and permanence to sound (bottom of graph). Among those who attributed only two properties of matter to sound (next to bottom row of graph), 15 attributed substantiality and weight (SW), but only three attributed substantiality and permanence (SP). Among the 32 who attributed only one property, 30 attributed substantiality (S). As can be seen at the top of the graph, 16 attributed none of the properties of matter (empty box). Inspection of the entire graph shows that there was a strong hierarchical relationship between the properties, which replicates what was observed in our previous study (Mazens & Lautrey, in press). The present study is not in itself sufficient to conclude that this hierarchical relationship corresponds to a developmental order in conceptual change, since we tested here only one age group (8-year-old). However, the fact that this relationship corresponded to a developmental order in our previous study (Mazens & Lautrey, in press), in which the participants were 6–10-year-old children, leads us to assume that the hierarchical relationship observed here corresponds to individual differences in the developmental steps of conceptual change within our 8-year-old group. It would be interesting to test this hypothesis on conceptual change in a more rigorous way in conducting a follow-up study using a longitudinal design. This hierarchical relationship was quantified here by a hierarchy index comparing observed and expected errors based on a Guttman scale.[2] This index varies between 0 when the items are not ordered more than at random, and 1 when they constitute a perfect Guttman scale. The value of this index was 0.80 for sound and 0.70 for heat. In addition, the comparison of the two graphs for sound and heat in Fig. 2 showed that this hierarchical relationship had the same form for the two concepts. In other words, if the children attributed the property of permanence, then they also attributed the properties of weight and substantiality. If the children attributed the property of weight to sound but not the property of permanence, then they also attributed the property of substantiality. The property of substantiality was attributed the most. These patterns are compatible with the assumption that, for both concepts, the properties of matter are generally abandoned in the following order: first permanence, then weight, and finally substantiality. For the three properties considered here and for this sample of 8-year-old children, this process of conceptual change occurred faster for sound than for heat (there were 16 children attributing none of these properties for sound while only four children did so for heat).

[2] $I = 1 -$ (observed errors/expected errors). The number of observed errors was the number of patterns observed in the sample that violated the expected hierarchy between the items. The number of expected errors was the number of such errors that could be expected if the subjects in that sample had responded at random. This index varied between 0 when there were as many errors as expected at random, and 1 when the items constitute a perfect Guttman scale (no observed errors). This index was proposed by Longeot (1969).

5. Discussion

The purpose of this study was to bring to the fore some empirical elements that could shed some light on two currently debated questions about children's naive knowledge, its consistency and the nature of conceptual change. More specifically, we aimed to replicate the results found in an earlier study on the concept of sound and to find out whether these results could be generalized to another concept in the same domain, heat.

Our qualitative analysis of the arguments used by the children pointed out the same categories of explanations for sound as in our previous research, and also the same categories for sound and heat. From these responses, we can infer the existence of the same mental models and naive theories that in our previous study on sound (see Introduction).

Our quantitative results concerning the children's consistency in attributing a given property to both sound and heat, showed that this attribution was massive for substantiality, medium for weight, and rare for permanence. The results concerning intraindividual consistency in the attribution of a given property always indicated a significant relationship between heat and sound. However, this significant relationship was sometimes weak. The kappa coefficients ranged from 0.13 to 0.32 for the weight, permanence, and substantiality properties, but were stronger for the trajectory properties (0.45 and 0.71).

In addition to these similarities for sound and heat, the results also pointed out some differences. In fact, substantiality, weight, and permanence were attributed somewhat more often to heat than to sound (10%–18% depending on the property considered) and this difference was always significant. A difference in the opposite direction, also significant, was observed for trajectories. This result can be tentatively interpreted as manifesting the role of experience in conceptual change. For the trajectory property, the children were more likely to represent simultaneous trajectories that went everywhere for heat than for sound, and thus seemed to have more advanced representations for heat. Our hypothesis is that this difference comes from the fact that everyday experiences with sound and heat are different. Heat is not perceived by a strictly localized receptor organ such as the ears, but by the whole body. Moreover, in daily life children can observe that heat not only spreads to people, but can make substances melt, heat up a space, etc. In short, the effect of heat on objects can be perceived whereas the effect of sound cannot.

But why do children more frequently attribute substantiality, weight, and permanence to heat than to sound? Two conjectures can be put forward here, one concerning the role of perception and the other the role of social transmission. Our conjecture concerning the role of perception is that heat seems to "stay" longer in objects than sound does. Moreover, many children seem to liken heat to steam, and some think that water becomes lighter when it cools down because the steam goes away. Insofar as steam is assimilated with heat, the fact that steam can be perceived may reinforce the attribution of the properties of matter to heat. Concerning the role of social transmission, we found that to explain how sound can pass through solids, the children used terms such as "resonate" or "vibrate" before being able to explain the physical phenomenon to which these words refer. Our conjecture is that through the use of these verbal expressions, children acquire a direct intuition about the mechanisms of sound transmission, and this intuition plays a guiding role in their search for explanatory hypotheses. There do not seem to be such helpful terms in the domain of heat transmission, and this difference could be another reason why children move slightly faster toward mental models of processes for sound than for heat (9 vs 2 in Table 1). This conjecture is in line with the position taken by Howe (1998), who following Vygotski, suggested that language and socio-cultural transmission can sometimes provide children with a more direct access to causal mechanisms than action, at least when the understanding of these mechanisms is situated inside what Vygotski called the proximal zone of development. Such differences in socio-cultural transmission between concepts are invoked by Howe to explain the lags she observed in conceptual change between heat transfer, propelled motion, and object floating. The same kind of explanation can be proposed here to explain the observed difference in the rate of conceptual change between heat transfer and sound transmission.

Part of the relative weakness of consistence in attributing a given property to the two concepts can be explained by the lags discussed above in the rates of conceptual change for heat and sound, but another part seems due to inconsistencies. In Table 1, for example, 25 children were in the cells below the diagonal, which means that they gave arguments of a lower level for heat than for sound, and thus went in the direction of the mean lag discussed above. But 13 children were in the cells above the diagonal, which means that they exhibited a lag in the opposite direction. These inconsistencies may mean that the developmental lag between the two concepts does not go in the same direction for all subjects, or that when a new mental model emerges, the preceding ones do not necessarily disappear and are still used in some situations. This latter hypothesis would be in line with the overlapping waves model proposed by Siegler (1996) to account for the lags observed in the development of cognitive strategies.

Concerning children's coherence in the attribution of the various properties to a given concept, the results demonstrate more coherence than between concepts. The kind of coherence found, however, was not due to the synchronic attribution of the various properties, but to a hierarchical relationship between these properties. Moreover, as can be seen in Fig. 2, the order of attribution of the properties was the same for sound and heat. Permanence was the first property to be abandoned, then weight, and finally substantiality.

Returning to the first question raised in the Introduction, that of the consistency of naive knowledge, the results of this study suggest that naive knowledge is not "in pieces". Some core foundational principles or framework theories that constrain children's understanding of physical phenomena can be inferred from their explanations. At the heart of their first naive theory is the presupposition that sound and heat are made of matter. Various mental models are then elaborated to reconcile children's daily observations with this presupposition (see Introduction). At the heart of the second framework theory is the presupposition that some entities are immaterial; they seem to keep the essence of "objects" without being constrained by the usual properties of matter. The corresponding mental model is based on socially transmitted myths, such as myths about ghosts, or by the experience of material entities (e.g., air), for which only some of the usual properties of matter can be perceived. Finally, at the heart of the third framework theory is the presupposition that sound or heat are no longer "objects" but a physical process in which "something" is transmitted. The corresponding mental model is based on examples of mediation and of transmission by adjacency, without a clear idea of exactly what is transmitted. It should be noted that this first theory of physical processes is still very far from the idea of "constraint-based interaction", which would be the appropriate scientific theory. It should also be noted that the idea that sound and heat are immaterial entities is apparently not a consequence of their allocation to the category of processes, but precedes it.

Thus, the five mental models and the three naive theories found in our earlier study on sound (see Introduction) were also identified in this study, not only for sound, but also for another concept of the same domain, heat. There appears to be a significant—but sometimes weak—relationship between the attribution of a given property to one concept and its attribution to the other, and the order in which these different properties are abandoned also seems to be the same for the two concepts. As a whole, these results suggest that naive knowledge is constrained by some foundational principles. They also support Chi's (1992) hypothesis according to which some misconceptions come from having assigned a concept to an inappropriate ontological category.

Concerning the second question, that of the mechanisms of conceptual change, the results of our developmental study (Mazens & Lautrey, 2000a,b, in press) and of the present study do not confirm the view that conceptual change occurs through a process of reallocation of a concept from one ontological category to another (so they do not support this part of Chi's hypothesis) or, if such a reallocation occurs, it seems to take years. Certain properties of matter, like weight and permanence are abandoned far before others like substantiality, which seems to persist for a long time. In the case of the two concepts studied here, conceptual change thus seems to be a very gradual process in which the different presuppositions linked to ontology have different degrees of resistance, depending on their centrality. This picture of conceptual change fits best with the idea that a change occurs through the revision of the fundamental presuppositions of a framework theory. The observed lags between heat and sound in the rate of this change, which we interpret as corresponding to differences in the perceptual experience that children can have of these two physical phenomena and differences in the support provided by language, also underline the role of everyday experience and of sociocultural transmission in the revision process.

6. Uncited reference

Vosniadou (1992).

Appendix A

See Table A1—A5.

Table A1
Substantiality, prediction for the metal box: number of arguments of each type, for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	25	14	1	0	40
Strength	10	18	3	0	31
Immaterial	2	1	1	0	4
Process	3	2	0	0	5
Total	40	35	5	0	80

Table A2
Substantiality, prediction for the cardboard box: number of arguments of each type, for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	29	17	1	1	48
Strength	10	17	1	0	28
Immaterial	1	0	0	0	1
Process	2	3	0	0	5
Total	42	37	2	1	82

Table A3
Substantiality, prediction for the wall: number of arguments of each type, for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	24	17	2	0	43
Strength	12	15	2	0	29
Immaterial	0	0	1	0	1
Process	2	6	0	0	8
Total	38	38	5	0	81

Table A4
Substantiality, observation for the metal box: number of arguments of each type for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	34	8	3	0	45
Strength	4	13	3	1	21
Immaterial	2	0	2	0	4
Process	5	3	3	1	12
Total	45	24	11	2	82

Table A5
Substantiality, observation for the cardboard box: number of arguments of each type, for sound and heat

Sound	Heat				Total
	Holes	Strength	Immaterial	Process	
Holes	34	8	1	1	44
Strength	7	18	2	1	28
Immaterial	1	0	0	0	1
Process	3	3	1	0	7
Total	45	29	4	2	80

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