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Transfert d'apprentissage chez les jeunes enfants : Magie du numérique ou rôle des similarités ?/Transfer of learning in young children: Magic digital or similarity-based?

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Abstract: Background. There is little information about the transfer of a problem-solving procedure presented on different tasks'modalities, especially between tangible and touchscreen. **Method.** One Hundred and three children aged 6 to 7 solved a first version of the ToH that was presented either through a tangible or a touchscreen modality, and then solved a second version which was also presented either through a tangible or a touchscreen modality. Besides, we measured the participants' levels of cognitive inhibition, as it may play a role in transfer. **Results.** The results showed that transferring the procedure was accompanied by a decrement in performance. This decrement was followed by a recovery of performance in the following trials. Performance on the first transfer trial was better within-dimension touchscreen condition rather than in cross-dimension tangible condition. Inhibition scores significantly predicted transfer performance. **Conclusion.** Transfer of learning is promoted by tasks' modalities similarity not by the digital itself, and cognitive inhibition predicts transfer performance.

Keywords*:* transfer of learning, touchscreen, Tower of Hanoi, cognitive inhibition.

Titre de l'article : Transfert d'apprentissage chez les jeunes enfants : Magie du numérique ou rôle des similarités ?

Résumé : Contexte. On dispose de peu d'informations sur le transfert d'une procédure de résolution de problèmes présentés sur des supports différents, en particulier entre les objets tangibles et la tablette numérique. **Méthode.** Cent trois enfants âgés de 6 à 7 ans ont résolu une première version de la ToH présentée soit sur support tangible, soit sur support numérique, puis ont résolu une seconde version également présentée soit sur un support tangible, soit sur un support numérique. Nous avons également mesuré l'inhibition cognitive des participants, car elle peut jouer un rôle dans le transfert. **Résultats.** Le transfert de la procédure s'accompagnait d'une baisse de performances. Cette baisse était suivie d'un regain de performances dans les essais suivants. La performance au premier essai de transfert était meilleure dans la condition numérique-numérique par rapport à la condition tangible-numérique. Les scores d'inhibition prédisaient significativement les performances au transfert. **Conclusion.** Le transfert d'apprentissage est favorisé par la similarité des supports de présentation et non par le numérique en soi et l'inhibition cognitive prédit les performances au transfert.

Mots-clés : transfert d'apprentissage, tablette numérique, Tour de Hanoï, inhibition cognitive.

Introduction

Since the work of Piaget (1967), we know that individuals build their knowledge through contact with their environment. Indeed, learning is a modification in the learner's knowledge, caused by experience. Nevertheless, for Mayer (2008), learning has three stages. First, the learner must extract from the stimulus the information relevant to learning. Then, he must organize the selected information into a coherent mental representation. Finally, he must integrate this information, i.e., relate it to the knowledge already present in Long-Term Memory (LTM). Thus, the individual's cognitive system is core in learning. The models that are part of the cognitive approach to learning, which guided our research, give a capital role to the organization of knowledge in memory, and to the role of memory in processing information when carrying out different tasks (Mayer, 2008; Sweller, van Merriënboer, & Paas, 2019). A common challenge in psychology and education is to find ways to help students to learn. In this aim, it is necessary to look at the way learning content is presented, in order to initiate appropriate cognitive processing during learning (Mayer, 2008). Any task being carried out on a tool, this one can play a role in knowledge acquisition of. From this perspective, multimedia learning theories argue that digital tools are a good way to enhance learning.

Learning on touchscreen

Touchscreen tablets have become an important part of children's daily lives, allowing them to create a personal environment tailored to their play and/or learning needs. The multitasking nature of touchscreen tablets arouses interest in children, as these devices offer the opportunity to entertain themselves at the same time as they learn. The tactile properties of the touchscreen tablets allow for intuitive use (Major, Haβler, & Hennessy, 2017), which makes tablets easy to use. This ease of use promotes learners' interactions with the screen, which

may enhance the role of touchscreen tablets in facilitating learning. Touchscreens contain a great haptic experience (Major et al., 2017). According to some researchers, the addition of a haptic modality when performing a task can lower cognitive load (Bara & Tricot, 2017), which is known to impede learning (Sweller, 1988; Sweller et al., 2019). The literature review conducted by Haßler et al., (2016) suggests that tablets have educational advantages. Indeed, out of 23 studies reviewed, 16 indicate a positive effect of the tablet on student learning. For the authors, the ease of use of the tablet, the multiplicity of functions it contains, the contingent interactions it allows, are all assets that make it pedagogically effective. However, this positive effect of the tablet on learning does not necessarily lead to the conclusion of a possible superiority over traditional educational tools. The studies that validate its effectiveness do not compare learning situations with tangible tasks. Moreover, if touchscreen tablets have been shown to be beneficial to children's learning, less is known about transfer of learning with tablets.

Transfer of learning from touchscreen tablets

Transfer of learning consists in the reuse, in a new transfer task, of a knowledge that was previously acquired in a main task (Barnett & Ceci, 2002; Helsdingen, van Gog, & van Merriënboer, 2011). Many studies showed that the quality of transfer is dependent on the nature and number of similarities between the main and the transfer task. This is a very general trend, which applies both in children (Brown & Kane, 1988) and adults (Gick & Holyoak, 1980). A high number of similarities between tasks increases the efficiency of transfer (Reed, 2012). Similarity can be observed between structural features and/or surface features. The structural features of a task are directly relevant to solve a problem (e.g., legal operators in the Tower of Hanoi task) and cannot be modified without consequences for successing in solving the problem; whereas the surface features refer to the "dressing" of the

task and are *salient* (e.g., the statement of a story) (Corbalan, Kester, & van Merrienboer, 2011; Gick & Holyoak, 1987).

Transfer of learning is also more likely when task similarity is combined with context similarity, as task similarity alone does not allow for optimal transfer (Klahr & Chen, 2011). The context refers to the learning domain and/or environment in which a task is embedded, including people, tasks' modality, and locations (Barnett & Ceci, 2002). With the emergence of digital devices, the tasks' modality must be extended to the proper format used for presenting the tasks, namely digital vs tangible. Digital tasks often include seductive details which compose a digital context of presentation, those details being non-essential for understanding the task and even sometimes detrimental (Park, Flowerday, & Brünken, 2015).

Furthermore, the law of similarities that governs the efficiency of transfer of learning makes necessary to distinguish near transfer from far transfer, according to the symbolic distance between tasks and contexts. Far transfer is defined by a low degree of similarity between tasks and between contexts. On the contrary, near transfer is defined by strong similarities of tasks and contexts (Barnett & Ceci, 2002). Many studies showed that, contrary to far transfer which is frequently failed, near transfer seems relatively easy to observe in children (Aladé, Lauricella, Beaudoin-Ryan, & Wartella, 2016; Henry, Messer, & Nash, 2014; Lorch et al., 2014; Moser et al., 2015; Riggs, Alibali, & Kalish, 2015; Zack, Gerhardstein, Meltzoff, & Barr, 2013). Frequent success of near transfer is easily attributable to the high degree of tasks' and contexts' similarities, which promote the identification of a common structure between the task, as well as the adaptation of the to-be-transferred knowledge. The more similarities between tasks and contexts, the less the need of adaptation, which enhances the probability of successful transfer (Nokes, 2009).

Another factor mentioned in the literature is a sufficient level of understanding of the structure of the main task, which is supposed to enhance transfer (Chi & VanLehn, 2012). A

way to improve deeper understanding of a task is to provide feedback. Feedback is essential for learning because its reception is not passive. It reminds the learner of his or her mistakes and makes him or her reflect on them, thus improving learning. It can also be useful for improving in subsequent similar, or more complex, tasks (see Wisniewski, Zierer, & Hattie, 2020, for a meta-analysis). Thanks to their touchscreens, digital tablets offer a great immersive experience, allowing for more direct interaction and more engagement in the task (Hirsh-Pasek et al., 2015; Robinson & Brewer, 2016). The engagement in the task is enhanced by the feedback which is instantly delivered by the tablet following the learner's actions. This, in turn, allows for deeper learning (Hirsh-Pasek et al., 2015).

Tasks' and contexts' similarities, as well as a deep understanding of the main task through feedback, are thus supposed to enhance the quality of transfer. Several studies showed, however, that despite the apparent easiness of near transfer, it is often accompanied by a decrement in performance (Adi-Japha & Brestel, 2020; Clerc & Miller, 2013; Clerc, Leclercq, Paik, & Miller, 2021b; Gellert, Arnbak, Wischmann, & Elbro, 2021; Pacton, Perruchet, Fayol, & Cleeremans, 2001; Resing, Bakker, Pronk, & Elliott, 2016). This also includes studies in which young children use touchscreens that are, yet, deemed to facilitate learning. These studies using touchscreens showed a specific case of decrement in performance at transfer, called transfer deficit (Hipp et al., 2017; Moser et al., 2015; Zack et al., 2013). The term " transfer deficit " has been proposed to express that young children learn consistently less from television, touchscreens, and books, than from face-to-face interactions (Moser et al., 2015), resulting in low transfer. Transfer deficit is problematic, given the central role that transfer plays in cognitive development and learning.

In the case transfer deficit occurs with a touchscreen tablet, it is desirable to use a bidirectional paradigm, in order to see if the transfer deficit is specifically linked to the digital device per se or if it comes from a dissimilarity between the two tasks'modalities (tangible vs

digital). The first study using touchscreens that introduced a bidirectional paradigm, tested cross-dimension transfer, either 2D/3D or 3D/2D (Zack, Barr, Gerhardstein, Dickerson, & Meltzoff, 2009). With this paradigm, 15-month-old participants were shown to correctly imitate a pressing gesture (pressing a button on a pig's nose) when required to use the same modality in the main and the transfer tasks in a within-dimensional design (near transfer, 2D/2D and 3D/3D); but they failed when the tasks' modalities were different, using a cross-dimensional design (far transfer, 2D/3D and 3D/2D). Developmentally, the transfer deficit has been shown to appear, in the case of transfer by imitation, around age 1, to peak around age 1.5, and to become less pronounced in children between 2 and 2.5 years of age (see Barr, 2010, for a review). Then, transfer deficit is observed again, beyond age 3, in problem-solving tasks like puzzle tasks (Moser et al., 2015). Less is known on the occurrence of transfer deficit after this age, so it is necessary to test for its occurrence in more complex problem-solving tasks in older children, in order to document the hypothesis of its long-lasting presence during childhood.

To address this concern, Huber et al. (2016) conducted a problem-solving study with 6-year-olds, based on the Tower of Hanoi (ToH) task. The ToH task is widely used in problem-solving literature, and children consistently struggle to perform this task throughout childhood (Klahr & Robinson, 1981). Moreover, difficulties in transferring problem-solving procedures between different versions of the ToH task have been noted in children aged until at least 8 (Klahr & Robinson, 1981; Schiff & Vakil, 2015), which justifies its use for the study of transfer of learning within a developmental approach. Huber et al. (2016) used two versions of the original ToH task, both containing three disks: a 2D touchscreen version serving exclusively as the main task, and a 3D tangible version serving exclusively as the transfer task. Children were asked to complete the task on four successive trials. One group performed the first three trials with the touchscreen version, and the fourth trial, considered the transfer

trial, was performed with the tangible version. A second, control, group, solved only the tangible version on all four trials. The results showed that, on the fourth trial, children who transferred from the touchscreen to the tangible modality (2D to 3D) performed at the same level as their peers who completed only the tangible (3D) version, thereby showing an absence of any transfer deficit. Replicating this study, Tarasuik, Demaria, and Kaufman (2017) observed the same pattern of stable performance on the transfer trial compared to the previous ones. However, in these two studies, only the tasks' modalities varied (2D vs 3D) but the two tasks used were strictly identical in any other concern, especially as to the stackable pieces (both tasks contained three disks). Such a paradigm is typically the one used when studying transfer by imitation in very young children (see Barr, 2010, for a review), but it is less adapted to the study of transfer in older children (Clerc, Leclercq, Paik, & Miller, 2021a; Moser et al., 2015). Indeed, transfer of learning in children aged 3 or more is reputed to occur between tasks that are, at least in some way, different, as in analogical transfer (Gentner & Colhoun, 2010; Chi & VanLehn, 2012) or strategic transfer (Chen & Klahr, 1999; Gamo, Sander, & Richard, 2010). It may be the case that transfer between two ToH tasks gives raise to transfer decrement if not only the modalities of both tasks (2D vs 3D) but also the proper components of the task, in this case the stackable pieces, differ. Moreover, as the number of differences between both tasks increase, the need for inhibiting some non-relevant elements is likely to increase too.

Inhibition in transfer of learning

Transferring knowledge from a main to a transfer task needs that it is adapted to the transfer task (Nokes, 2009; Schwartz, Chase, & Bransford, 2012). It raises the question of the cognitive processes underlying adaptation. The adaptive dimension of transfer requires that the structure of the main task be mastered in depth, so that the knowledge can be reused in the new transfer task (Chi & VanLehn, 2012; Nokes, 2009), involving efficient metacognitive

(Bjorklund, & Causey, 2017; Winne, 2011) and executive processes (Clerc, Miller, & Cosnefroy, 2014; Pauen & Bechtel-Kuehne, 2016). Executive functions are a set of control processes that allow for regulating one's thoughts and behaviors when facing novel situations (Miyake & Friedman, 2012), including inhibition, working memory, and flexibility (Diamond, 2013). These three, so-called "fundamental", executive functions, seem to develop at different rates (Fujisawa, Todo, & Ando, 2017) and overlap during childhood (Miller, Giesbrecht, Müller, McInerney, & Kerns 2012; Usai, Viterbori, Traverso, & De Franchis, 2014). Furthermore, a growing body of research shows a specific facilitating role of inhibition abilities for learning (Borst, Ahr, Roell, & Houdé, 2015; Hulbert & Anderson, 2008, Lubin, Lanoë, Houdé, & Borst, 2013; Simpson et al., 2019). Inhibition would facilitate learning by allowing a child to suppress inappropriate heuristics, and replace it by algorithmic thinking, thus causing a better adaptation (Houdé & Borst, 2015).

A specific kind of inhibition which is likely to facilitate transfer is interference control. According to Diamond (2013), interference control is a sub-component of inhibitory control, which appears to be involved in adaptation to a transfer task (Roell, Viarouge, Houdé, & Borst, 2019; Thibaut, French, Vezneva, Gérard, & Glady, 2011). Interference control may facilitate adaptation to the transfer task, by allowing a child to ignore the irrelevant dissimilarities between the surface features of the two tasks and between their contexts (Clerc et al., 2014; Pauen & Bechtel-Kuehne, 2016). Indeed, such dissimilarities give rise to interferences that must be controlled to limit their negative effects on the resolution of the transfer task.

Present study

Studies by Huber et al. (2016) and Tarasuik et al. (2017) showed that, despite the change in modalities (2D-3D), children's performance did not decline when switching from the main task to the transfer task. Nevertheless, in these studies, only the tasks' modalities differed

between the main (2D) and the transfer (3D) task. Tasks' modalities are only a contextual element however, and not a task element per se. This may explain why no transfer deficit was observed, appealing for replicating these studies including a proper change between the two tasks, and not only between their modalities (2D vs 3D). This may advance our understanding of transfer of learning when using a touchscreen tablet, since in these two studies no transfer deficit was observed, whereas it has been observed on several occasions in transfer studies using tangible tasks in school-aged children (Adi-Japha & Brestel, 2020; Clerc et al., 2013, 2021b; Elsner & Schellhas, 2012; Gellert et al., 2021; Resing et al., 2016; Detable & Vinter, 2006). Slight differences between the surface features of the main and the transfer tasks may indeed hinder transfer (Green, Strobach, & Schubert, 2014), which could lead to the occurrence of the transfer deficit phenomenon and explain why this phenomenon was not observed in the two studies reported above. In other words, is transfer including both a tangible task and a digital task presented on a touchscreen tablet, more successful than transfer using only tangible tasks, or does it also obey the law of similarities and sometimes lead to transfer deficit?

Finally, transfer of learning gives rise to different patterns of success or failure, depending on which transfer trials were succeeded or failed along a multiple-trials transfer task (Chen & Klahr, 1999). This raises the question of the temporal evolution of performance between the first transfer trial and several subsequent transfer trials. Such an approach could provide a better understanding of the intra-individual variability in transfer of learning, and its progression as the learner practices a task. For this reason, in this study, trials are a variable of interest. We studied the transfer of an action procedure between a digital and a tangible version of the Tower of Hanoi task in 6-year-old children. The present study has four objectives, 1) Replicating the study of Huber et al. (2016) while replacing the stackable disks by stackable squares in the main task, to see whether this slight difference in surface elements

between both tasks can cause a decrement in transfer performance, 2) testing the hypothesis that the similarity of tasks' modalities, respectively tangible and digital, allows to resist to this decrement in performance, 3) investigating the temporal dynamics of performance during the learning trials and the transfer trials, 4) extending the result of a facilitative role of inhibition in transfer, by using transfer situations including tangible and digital tasks, these tasks' modalities acting as contextual features.

Thus, we hypothesized a decrement in transfer performance between the two versions of the ToH (H1). Referring to Klahr and Chen's (2011) model, we also hypothesized that the decrement in transfer performance would be less pronounced when the tasks are presented in the same modality (H2). We also assumed that this decrement would be localized at the first transfer trial, and would be followed by a rebound in performance in the following transfer trials, when adaptation to the transfer task becomes easier as trials succeed each other (H3). A final hypothesis is that the decrement in transfer performance should be more pronounced in children with lower inhibition skills (H4).

Method

Participants

One hundred and three children (M_{age} = 6.7, SD_{age} = .45; 51 males) from two elementary school in Libreville (Gabon) participated in this study. According to the information provided by the parents and teachers, no child showed signs of atypical development or cognitive or learning disorders.

Material

Different versions of the Tower of Hanoi were presented either on an acer Iconia One 10 B3-A40-K2AM touchscreen tablet (screen size resolution 1280×800, length 258 mm, width 167.5 mm, height 9.15 mm) or with wooden objects.

Task

The task used in this study is the three-stackable Tower of Hanoi. The stackable are stacked from the largest to the smallest on the left location, and the goal of the task is to reconstitute this configuration on the right location by passing through an intermediate location if necessary. To solve the ToH, there are rules to follow: one can only move one stackable at a time, one can only put a stackable onto a larger stackable or on an empty location. ToH task needs at least seven moves to be correctly performed. Using very identical tasks, Huber et al. (2016) showed that changing modalities from 2D to 3D did not decrease transfer performance. This pattern was again observed when Tarasuik et al. (2017) replicated the study by Huber et al. (2016). For this reason, for the sake of parsimony, we did not use very identical tasks as in these two studies. Instead, we varied the tasks, aiming to see if slight differences in the tasks' features can make the performance decrease at transfer. Thus, four versions were used for this study: two touchscreen versions (one with three squares and one with three disks) and two tangible versions (one with three squares and one with three disks).

Touchscreen version of the Tower of Hanoi with three squares

This task is a touchscreen version of the classic Tower of Hanoi in which the pegs are replaced by planks (Figure 1). It consists of three squares of different sizes and colors (a small red square, a medium green square, and a large purple square) and three planks laid horizontally on the floor. For this study, we used a version downloaded from Playstore (developed and updated by Skarcat Studios in 2016, © Google 2017), including grass, trees, a goat and a cabin as background elements. To move the squares, the participant must touch the square he has chosen, then touch the plank he wants to move the square to. The touchscreen provides the participant with corrective feedback: when a square is placed on a smaller one, it

is immediately and systematically returned to its original location before the game can be restarted.

Figure 1. Touchscreen version of the Tower of Hanoi with three squares

Touchscreen version of the Tower of Hanoi with three disks

This task consists of a horizontal support with three vertical pegs on which three disks with holes in the middle can be threaded, including a small green disk, a medium red disk, and a large yellow disk (Figure 2). Each peg is colored at the top with one of the three colors of the disks, in order to create perceptual distractors whose goal is to solicit inhibition capacities. The disks are stacked from the largest to the smallest on the left peg, and the goal of the task is to reconstitute this configuration on the right peg. We used a version downloaded from Playstore (developed and updated by GRuV Studios in 2017, © Google 2017), including a blue wall and a tiled floor as background elements. To move the disks, the participant touches the chosen disk with their finger, slips it into the chosen peg by sliding it. As in the three-squares version, the touchscreen provides the participant with corrective feedback: when a disk is placed on a smaller one, it is immediately and systematically returned to its original location before the game can be restarted.

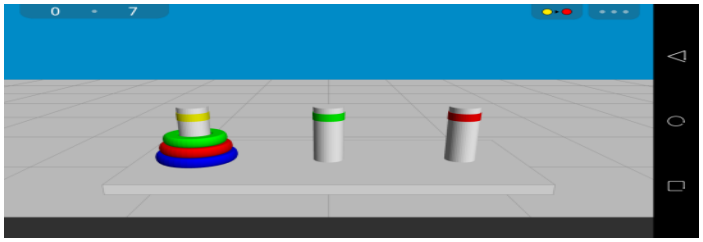

Figure 2. Touchscreen version of the Tower of Hanoi with three disks

Tangible version of the Tower of Hanoi with three squares

This task was constructed for experimental purpose. It consists of three squares of different sizes and colors (small: 5.5cm, yellow; medium: 7.5cm, brown; large: 9.5cm, green), and a wooden plank containing three rectangular locations (width 15cm; length, 17cm) aligned horizontally (Figure 3). The purpose is the same as in the touchscreen versions with three squares described above. In this version, the feedback was provided by the experimenter when the child broke a rule (the experimenter returned the square to its previous location).

As can be seen on figures 1 and 2, both touchscreen tasks included contextual elements, animal and trees for the three squares version, and several colors in the three disks version. This was intended to accurately reproduce the frequent contextual elements that are present in many educative apps, and which are often detrimental to learning (Park et al., 2015).

Figure 3. Tangible version of the Tower of Hanoi with three squares

Tangible version of the Tower of Hanoi with three disks

This task consists of three disks of different sizes and colors (small: diameter 2cm, green; medium: diameter 3cm, brown; large: diameter 4cm, yellow), and a wooden plank (length: 20cm, width: 7.5cm) topped by three pegs (height: 9cm), *cf.* Figure 4. The pegs have at their tops different colors corresponding to the color of each disk, the goal being to create perceptual distractors as in the touchscreen version with three disks. The purpose is the same as in the touchscreen versions with three disks described above. In this version, the feedback

was provided by the experimenter when the child broke a rule (the experimenter returned the disk to its previous location).

Figure 4. Tangible version of the Tower of Hanoi with three disks

Day and Night inhibition test (Gerstadt, Hong, & Diamond, 1994)

This is a dominant response suppression test. It contains two types of paper cards, representing either the moon or the sun (Figure 5). In the first phase, six cards (three "sun" cards and three "moon" cards) are lined up on the table in random order, face down. The first card is turned over by the experimenter and the child must provide the associated verbal response, "day" if the card represents the sun and "night" if it represents the moon. The card is then turned face down and the second card is revealed, and so on until the sixth card has been reached. In the second phase, the child must inhibit the verbal response associated with the card and provide the antagonistic verbal response. For example, the child must say "day" when the card represents the moon and "night" when it represents the sun. This phase begins with two practice trials (one "day" and one "night"), during which, if the child hesitates, the experimenter calls him or her back once, saying, "What should you say for this card?". The cards are then presented twenty-six times, one by one in a random order (50% "day"). The score is 1 point for a correct answer and 0 for an incorrect answer (maximum score 26). High scores indicate a strong capacity for cognitive inhibition. This task has been chosen because it belongs to the interference control part of inhibitory control (Diamond, 2013). Furthermore, it is easy to administrate, it does not require any digital apparatus, and it has been successfully

used for measuring cognitive inhibition in young children (Diamond, Kirkham, & Amso, 2002; Simpson et al., 2012; Simpson & Riggs, 2005; Thibaut et al., 2011).

Figure 5. Cards of Day and Night inhibition test

Procedure

The children were met individually in a room within their school on two consecutive days. On the morning of the first day, the child was asked to solve the three-squares ToH (main task), either in the tangible or in the digital (touchscreen) modality. In the afternoon, the child was asked to solve the three-disks ToH (transfer task), either in the tangible or in the digital (touchscreen) modality. Four experimental conditions were created, depending on the modalities used in the main task and in the transfer task, two within-dimension conditions and two cross-dimension conditions. The two within-dimension conditions were defined by the fact that the main task and the transfer task had the same modality, either touchscreen (2D/2D) or tangible (3D/3D), which defines a near transfer situation. The two cross-dimension conditions were defined by the fact that the main task and the transfer task had different modalities, either touchscreen-tangible (2D/3D) or tangible-touchscreen (3D/2D), which defines a far transfer situation. Participants were randomly assigned to one of the four conditions. Last, on the morning of the second day, the child performed the inhibition test.

Main Task: ToH with three squares

The child was seated, and on the table in front of him was the three-squares version, either wooden (tangible modality) or presented on the touchscreen tablet (digital modality). To ensure that the children understood the rules, as well as to obtain a baseline measure of their performance, a learning trial was co-realized between the experimenter and the participant (Richard, 1982). The experimenter provided the rules while demonstrating an allowed move ("You can only move one square at a time", the experimenter then moved the small square to the right location) ; then a forbidden move ("You cannot put a large square on top of a smaller one", the experimenter then moved the middle square on the top of the small one and immediately returned it to its original location). The child was then invited to continue the trial to the end. In the touchscreen version, feedback was provided by the tablet to the participant each time he or she broke a rule (the square was automatically returned to its previous location), along with an explanation from the experimenter (e.g., "the square is returned because you cannot put a large square on top of a smaller square"). For the tangible version, feedback was provided by the experimenter when the child broke a rule (the experimenter put the square back to its previous location), and the rule was reminded to the child (e.g., "I put the square back where it was, because you cannot put a big square on top of a smaller square"). The participant then had to perform four trials on his own, in one go. To let the child learn the procedure freely, there was no time limit, the trial ended, when the task was solved.

Transfer task: ToH with three disks

We chose to have this task solved in the afternoon, to limit the cognitive load that could be generated by the successive resolution of several trials. This method has previously been used in transfer of memory strategies studies (Clerc et al., 2013; 2021). The child performed the three-disks ToH, without prior training and without any mention of the three-squares ToH

performed in the morning. Again, either the wooden version (tangible modality) or the touchscreen version (digital modality) was proposed. The experimenter explained the rules to the child, but no feedback was given anymore. In the tangible version, if the child broke a rule, the experimenter returned the disk to its previous location without providing any explanation. In the touchscreen version, if the child broke a rule, the disk was automatically returned to its previous location and the experimenter did not provide any explanation. The child had to complete four trials in one go. Except for the very first co-performed trial in the main task, the transfer trials were performed with the same formalities as the learning trials (rules, feedback, no break between the trials, no time limit).

Results

Each child was assigned to one of four conditions, within-dimension 2D/2D (n = 27, M_{age} = 6.69, SD_{age} = .40), within-dimension 3D/3D (n = 24, M_{age} = 6.86, SD_{age} = .41), cross-dimension 2D/3D (n = 24, M_{age} = 6.78, SD_{age} = .50), and cross-dimension 3D/2D (n = 28, M_{age} = 6.67, SD_{age} = .38). There was no significant difference between the age means in the four groups $F(3, 99) = 1.11$, $p = .35$, $\eta^2p = .03$.

For all versions of the ToH, we measured the total number of moves required to solve the task, corresponding to all action sequences performed to complete the task. Below we present the performance on the main (4 trials) and transfer (4 trials) tasks (see Table I). Results were processed by analysis of variance, and planned comparisons were performed to locate the origins of significant differences. Furthermore, because the number of moves performed to complete the task is proportional to the resolution time, we only analyzed the number of moves. Furthermore, in previous studies with the ToH, time per move was obtained by dividing the total time by the number of moves (Huber et al., 2016; Schiff & Vakil, 2015), which does not seem to be relevant. In a deadlock situation, for example, children are likely to hesitate to perform a move, which frequently results in a longer time than for a successful

move (Clément, 2003). Thus, not all moves are performed with the same speed, the first move being likely to be slower than the last ones, due to the increasing understanding of the task as it is performed. For this reason, we chose to present only the correlations between the number of moves needed to perform the task, and the time taken to do so (see Table II).

Table I. Means and Standard Deviations for the number of moves, in each condition and in both main and transfer tasks' trials

Trial	Condition	*M*	*SD*	*N*
		Main task		
1	Within-dimension 2D/2D	24.19	9.72	27
	Within-dimension 3D/3D	31.92	16.05	24
	Cross-dimension 2D/3D	26.96	8.99	24
	Cross-dimension 3D/2D	26.79	12.19	28
2	Within-dimension 2D/2D	17.04	8.53	27
	Within-dimension 3D/3D	22.75	8.03	24
	Cross-dimension 2D/3D	21.33	7.18	24
	Cross-dimension 3D/2D	20.57	11.75	28
3	Within-dimension 2D/2D	13	7.58	27
	Within-dimension 3D/3D	16.88	11.65	24
	Cross-dimension 2D/3D	13.92	4.74	24
	Cross-dimension 3D/2D	19.75	9.94	28
4	Within-dimension 2D/2D	11.26	5.47	27
	Within-dimension 3D/3D	15.21	7.47	24
	Cross-dimension 2D/3D	13.83	6.16	24
	Cross-dimension 3D/2D	16.78	9.32	28
		Transfer task		
1	Within-dimension 2D/2D	22.63	9.33	27
	Within-dimension 3D/3D	27.04	10.30	24
	Cross-dimension 2D/3D	31.79	15.54	24
	Cross-dimension 3D/2D	31.36	11.81	28
2	Within-dimension 2D/2D	14.59	6.87	27
	Within-dimension 3D/3D	16.13	4.79	24
	Cross-dimension 2D/3D	15.67	5.92	24
	Cross-dimension 3D/2D	24.61	11.62	28
3	Within-dimension 2D/2D	13.33	9.29	27
	Within-dimension 3D/3D	15.88	11.31	24
	Cross-dimension 2D/3D	19.58	11.12	24
	Cross-dimension 3D/2D	19.53	12.74	28
4	Within-dimension 2D/2D	11.11	6.09	27
	Within-dimension 3D/3D	12.75	6.58	24
	Cross-dimension 2D/3D	15.92	9.41	24
	Cross-dimension 3D/2D	16.42	10.89	28

M = Mean, SD = Standard-Deviation, N = Sample

Analysis of moves

A mixed-measures Anova 2 (task, within-subjects) * 4 (trial, within-subjects) * 4 (modalities' similarity, between-subjects) was performed on the number of moves produced. The main effect of task is not significant, $F(1, 99) = .19$, ns., $\eta^2p = .01$. The main effect of trial is significant, $F(3, 297) = 151.93$, $p < .001$, $\eta^2p = .61$. Planned comparison showed that, overall, performance increased from trial 1 ($M = 27.83$, $SE = .94$) to trial 4 ($M = 14.27$, $SE = .62$), $p < .001$. The main effect of the modalities' similarity is significant, $F(3, 99) = 3.61$, $p < .02$, $\eta^2p = .09$. The number of moves in the 2D/2D condition ($M = 15.89$, $SD = 7.86$) is significantly lower than in the 2D/3D condition ($M = 21.98$, $SD = 11.28$), $p = .006$. No other difference was significant.

The task * trial interaction is significant, $F(3, 297) = 3.04$, $p = .03$, $\eta^2p = .03$. Planned comparisons were conducted between each trial of the main task. The children made significantly fewer moves to perform the second trial (M =20.33, $SD = 11.75$) than the first trial ($M = 27.34$, $SD = 12.14$), $p < .001$, then they made significantly fewer moves to perform the third trial (M =15.95, $SD = 9.16$) than the second, $p < .001$, and made significantly fewer moves to perform the fourth trial ($M = 14.28$, $SD = 7.49$) than third. Although the same pattern was observed in the transfer task ($M = 28.16$, $SD = 12.32$ to $M = 14.06$, $SD = 8.70$) there were slight differences with a performance recovery. When the four trials were compared to each other, the children made significantly fewer moves to perform the second transfer trial (M =17.92, $SD = 8.83$) than the first, $p < .001$. Performance was not significantly different between the second and the third ($M = 19.54$, $SD = 12.75$) transfer trials. It increased significantly from the third transfer trial to the fourth, $p < .001$, reflecting a continued recovery in performance.*cf*. Figure 6. To test the hypothesis of a decrement in performance when switching to the transfer task, we conducted a post-hoc test with Bonferroni correction between trial 4 of the main task and trial 1 of the transfer task. A decrement in performance

was observed, with the first transfer trial resulting in a significantly higher number of moves than the fourth trial of the main task, $p < .001$. As mentioned just above, a continuous recovery of performance was observed in the transfer task.

The task * modalities' similarity interaction is significant, $F(3, 99) = 3.43$, $p = .02$, $\eta^2p = .09$. There were no significant differences between the four conditions on any trial of the main task, suggesting that the four conditions were of equivalent difficulty in the main task. Conversely, in the transfer task, children in the 2D/2D condition ($M = 17.95$, $SD = 6.69$) make fewer moves than children in the 2D/3D ($M = 20.74$ $SD = 7.79$) and the 3D/2D ($M = 22.98$, $SD = 9.72$) conditions, ps = .03. Other differences were not significant.

The trial * modalities' similarity interaction is not significant, $F(9, 297) = 1.06$, ns., $\eta^2p = .03$.

The task * trial * modalities' similarity interaction is significant, $F(9, 297) = 2.36$, $p = .014$, $\eta^2p = .07$. To test the hypothesis that the decrement in transfer performance should be less pronounced when the tasks' modalities (tangible vs digital) are similar, we compared, at each trial in the transfer task, the results obtained in each of the 4 conditions. On the first transfer trial, children in the 2D/2D condition ($M = 22.63$, $SD = 9.33$) make fewer moves than children in the 2D/3D ($M = 31.80$ $SD = 15.54$) and the 3D/2D ($M = 31.36$, $SD = 11.81$) conditions, ps < .001. Other differences were not significant, especially the difference between the 2D/2D and the 3D/3D conditions. On the second transfer trial, children in the 3D/2D condition ($M = 24.61$, $SD = 11.62$) make more moves than their peers in the 2D/3D ($M = 15.67$, $SD = 5.92$), the 3D/3D ($M = 16.13$, $SD = 4.80$), and the 2D/2D ($M = 14.60$, $SD = 6.87$) conditions, ps < .001. The other differences were not significant. In the third and the fourth transfer trials, no significant difference appeared between conditions.

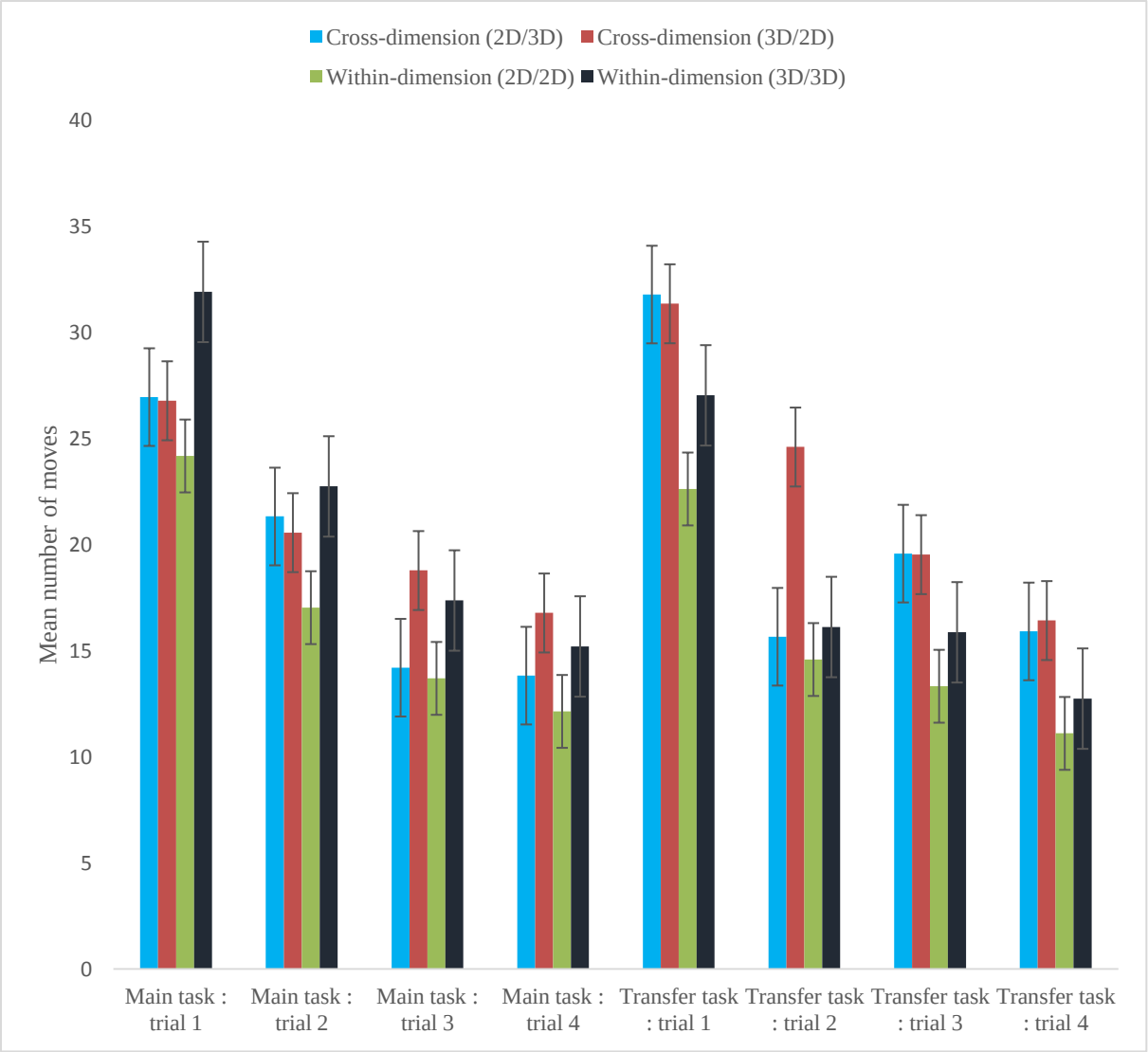

Figure 6. Mean number of moves on each trial as a function of modality type. Error bars represent standard errors.

Individual profile analyses

Although the average number of moves was nearly divided by two in the main task, between the first trial (*M* = 27.34, *SD* = 12.14) and the fourth trial (*M* = 14.28, *SD* = 7.49), the mean performance in the fourth trial still was twice as much as the optimal resolution of the ToH task which is 7 moves. Such a high number of moves at the end of the main task may explain the decrement at the transfer task, by a superficial understanding of the main task and of the procedure to be used. Indeed, one could assume that, at the fourth trial of the main task,

children had not yet acquired the optimal problem-solving procedure, which did not allow for spontaneous transfer and thus lead to a decrement in performance in the first transfer trial. On the other hand, if children who performed the fourth trial of the main task with the optimal 7 moves procedure, also showed a decrement at transfer, one may rule out this explanation. Therefore, we conducted individual trial-by-trial analyses, in order to see if different individual profiles would emerge beyond the average performance.

Based on the central tendency parameters (median = 12, mean = 14.28) and the optimal 7 moves procedure, we divided the sample into four (4) groups. Then, in each group, we conducted Hierarchical clustering method to identify the different profiles contained in each group. For the sake of parsimony and synthesis of results, we present the clusters with dendrograms.

Group 1: Children who completed trial 4 of the main task in 7 moves.

Seventeen children solved the fourth trial of the main task in 7 moves. Their performance systematically decreased when they switched to the first trial of the transfer task. The cluster analysis revealed two clusters (Figure 7) which thus constitute two types of profiles. Depending on the profile, the decrement in performance was not of the same magnitude. Two patterns were observed: a very strong decrement very strong gain (cluster 1), a strong decrement less gain (cluster 2). Thus, transfer decrement was observed in all children mastering the optimal 7 moves procedure at the end of the main task. It is important to note that these declines were followed by a rebound in performance, which was maintained until the end of the transfer task, in the very strong decrement very strong gain profile. In contrast, in the strong decrement less gain profile, this rebound in performance was followed by a decrement and then a rebound at the end. Figure 7 shows examples of these profiles.

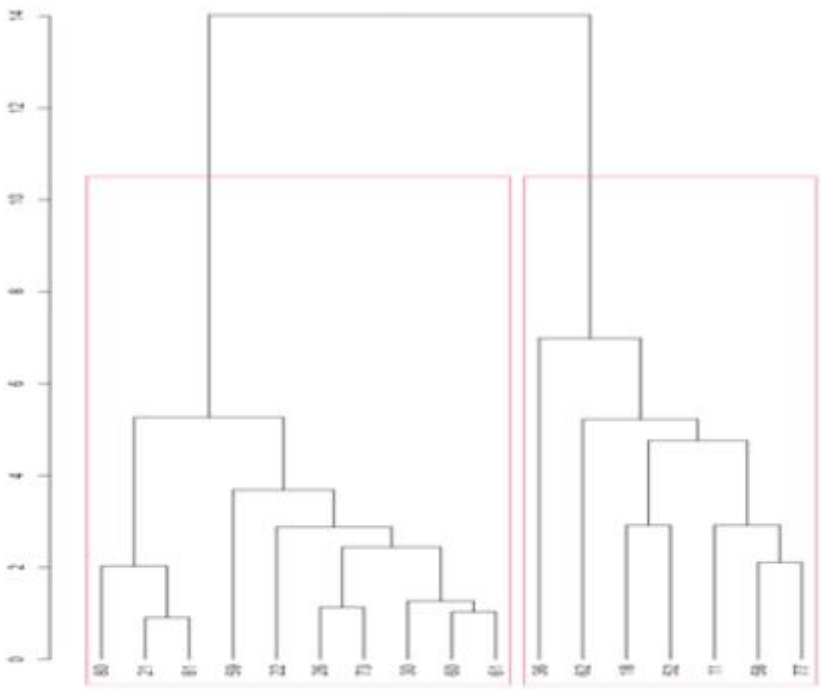

Figure 7. Dendrogram representation for clusters of children who acquired the procedure as a main task. From left to right cluster 1 (10 children) and cluster 2 (7 children).

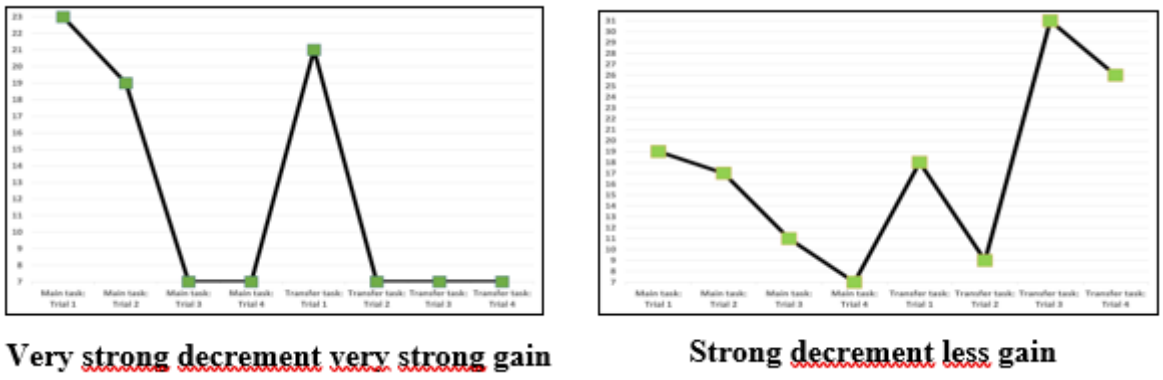

Figure 8. Patterns of the profiles of children who acquired the procedure as a main task.

Group 2: Children who completed trial 4 of the main task between 8 and 11 movements. This group was selected based on the central tendency parameters (median = 12, mean = 14.28). It is characterized by a number of moves which stands below these parameters.

Thirty children were concerned. The cluster analysis revealed four clusters (Figure 9) which constitute four types of profiles. One profile is similar to the second profile that was found in children who had acquired the optimal procedure of 7 moves, namely the strong decrement less gain profile (cluster 1). Three other profiles appeared: a less decrement constant gain profile (cluster 2) which is characterized by a less pronounced decrement at the beginning of the transfer task followed by a constant gain; a very strong decrement profile (cluster 3) which is characterized by a very pronounced decrement observed at the beginning and at the end of the transfer task; and a very strong decrement less gain profile (cluster 4) which is characterized by a very pronounced decrement at the beginning of the transfer task and a slight gain at the end of transfer. Among these four profiles, only children pertaining to the less decrement constant gain profile ended by mastering the optimal 7 moves procedure at the third and fourth trial of the transfer task. Children from the other three profiles ended the transfer task with a low performance visible in a high number of moves. We present examples of these profiles in the figure 10.

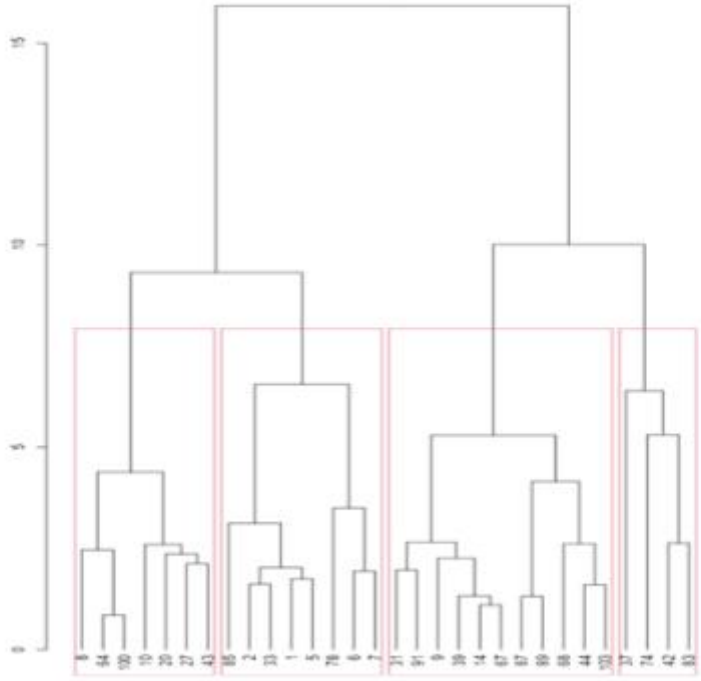

Figure 9. Dendrogram representation for clusters of children who of children solving the last trial of the main task between 8 and 11 moves. From left to right cluster 1 (7 children), cluster 2 (8 children), cluster 3 (11 children), and cluster 4 (4 children).

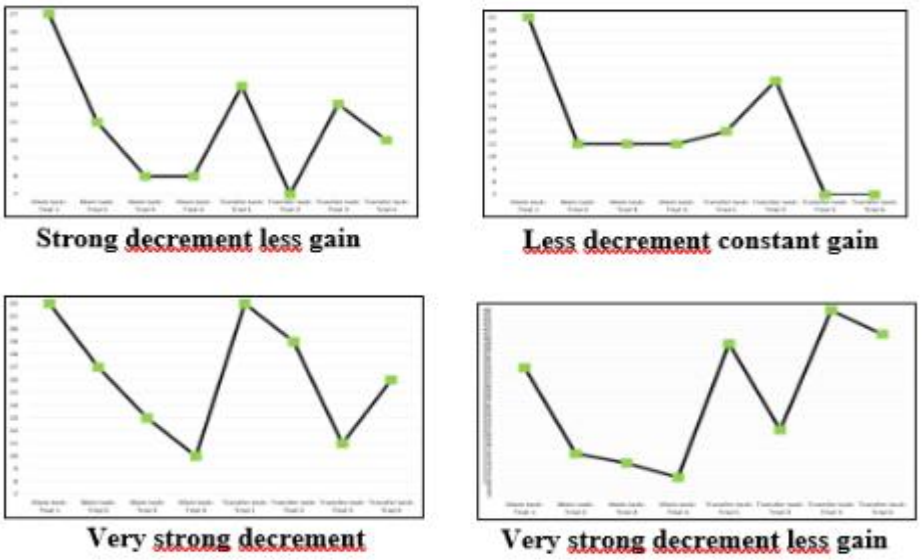

Figure 10. Patterns of the profiles of children solving the last trial of the main task between 8 and 11 moves.

Groupe 3: Children who completed trial 4 of the main task between 12 and 14 movements. This group was used as a basis to create groups 2 and 4, as it incorporates the central tendency parameters (median = 12, mean = 14.28).

Fifteen children were concerned. Cluster analysis revealed four clusters (figure 11) which constitute four types of profiles. One profile is similar to the first profile that was found in children who had acquired the optimal procedure of 7 moves, namely the very strong decrement very strong gain (cluster 2); and another one is similar to the second profile that was found in children who solved the last trial of the main task between 8 and 11 moves, namely less decrement constant gain (cluster 3). Two other profiles appeared, an alternate decrement gain profile (cluster 1) which is characterized by a decrement at the transition to the transfer task followed by a gain, then a decrement, then a gain at the end of the transfer; and a strong decrement constant gain profile (cluster 4) which is characterized by a very pronounced decrement observed at the transition to the transfer task, followed by a constant gain until the end of the transfer task. Transfer decrement between the fourth trial of the main task and the first trial of the transfer task was observed in all the four profiles. Among these four profiles, only children pertaining to the alternate decrement gain profile ended in a high number of moves at the fourth trial of the transfer task. Children from the other three profiles ended the transfer task with a high performance visible in a low number of moves. We present examples of these profiles in the figure 12.

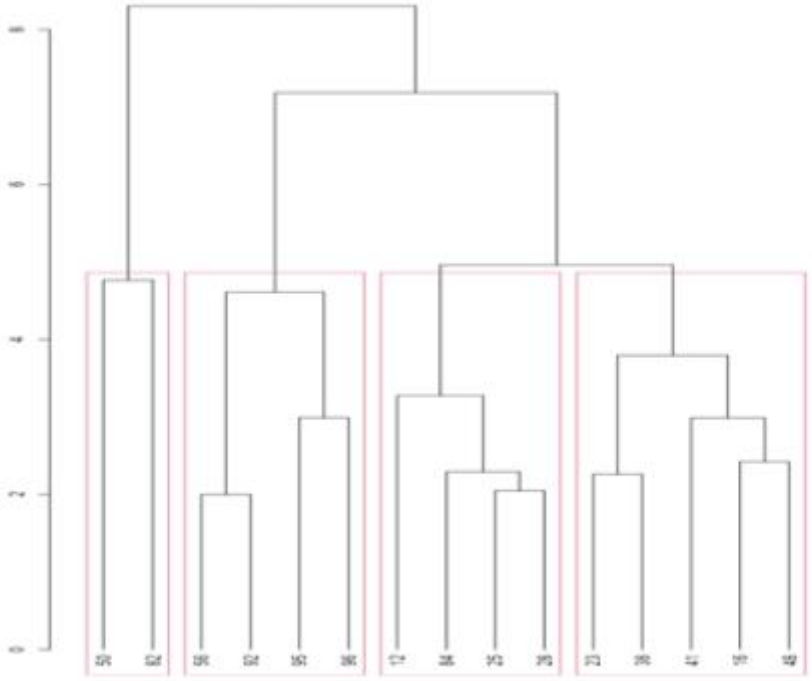

Figure 11. Dendrogram representation for clusters of children who solving the last trial of the main task between 12 and 14 moves. From left to right cluster 1 (7 children), cluster 2 (8 children), cluster 3 (11 children), and cluster 4 (4 children).

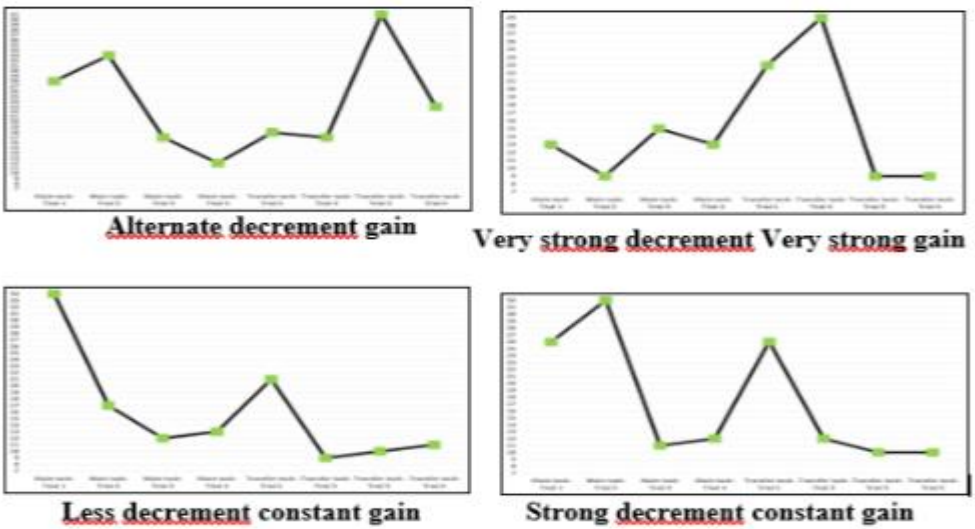

Figure 12. Patterns of the profiles of children solving the last trial of the main task between 12 and 14 moves.

Group 4: Children who completed trial 4 of the main task in 15 movements or more. This group was above the central tendency parameters (median = 12, mean = 14.28).

Forty-one children were concerned. These children can be considered as having only a limited, superficial, understanding of the task and of the procedure to be used. The cluster analysis also revealed four clusters and thus four profiles. Two profiles are similar to the first two profiles that were found in children who solved the last trial of the main task between 12 and 14 moves, namely alternate decrement gain (cluster 2) and very strong decrement very strong gain (cluster 4). Two other profiles appeared: a constant decrement profile which is characterized by an overall low constant performance until the end of the transfer task (cluster 1); and an alternate gain profile (cluster 3) characterized by constant/gain/decrement/gain succession, that we called alternate gain. Note that only children pertaining to the very strong decrement very strong gain profile ended by mastering the optimal 7 moves procedure at the third and fourth trial of the transfer task. Children from the other three profiles ended the transfer task with a low performance compared to the optimal 7 moves procedure. Nevertheless, a transfer decrement between the fourth trial of the main task and the first trial of the transfer task was observed in all the profiles. The figure 14 presents examples of these four profiles.

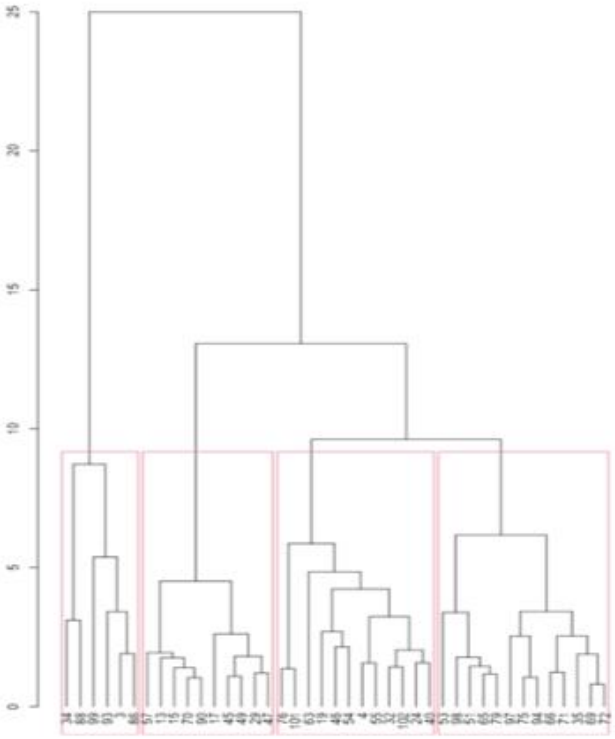

Figure 13. Dendrogram representation for clusters of children who of children solving the last trial of the main task in 15 and more moves. From left to right cluster 1 (6 children), cluster 2 (10 children), cluster 3 (12 children), and cluster 4 (13 children).

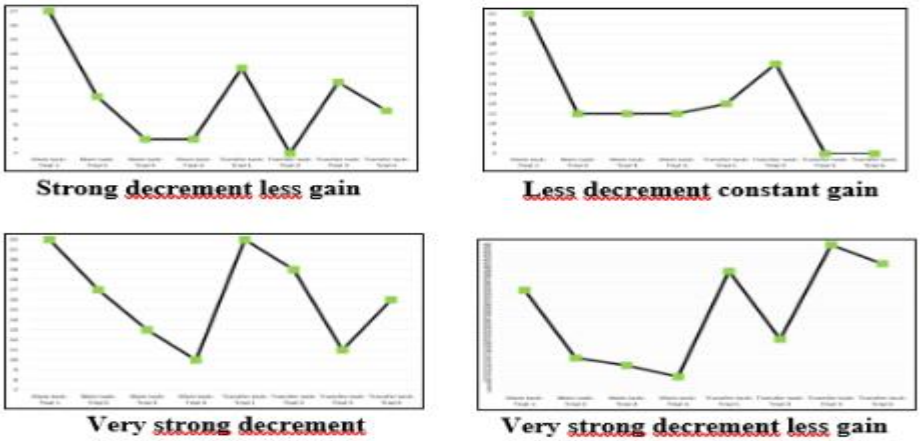

Figure 14. Patterns of the profiles of children solving the last trial of the main task in 15 and more moves.

This trial-by-trial analysis showed thus that, when dispatching our original sample in different individual profiles, transfer decrement was observed in nearly all of them, including the children who performed the last trial of the main task with the optimal 7 moves procedure. Furthermore, only two profiles ended the transfer task by mastering the optimal 7 moves procedure (namely less decrement constant gain and very strong decrement very strong gain profiles). Most profiles are characterized by a very high number of moves at the fourth trial of the main task: this may have prevented the performance to even more decrease, since it was already very low.

Correlation analyses

Correlation analyses were conducted to test for a relationship between the number of moves and the resolution time (see Table II). On each trial, the resolution time was positively and significantly correlated with the number of moves performed, with correlations ranging from .76 to .95 Furthermore, the resolution times on each of the 8 trials were correlated with each other, with only 1 non-significant correlation observed between pretest trial 2 and transfer trial 1 (compared to 27 significant correlations). The results are the same for the number of moves, with only 1 non-significant correlation observed between pretest trial 1 and transfer trial 2 (versus 27 significant correlations). Taken together, these results show a strong consistency between the number of moves and the resolution times on all trials, and justifies that, for the sake of parsimony, we analyzed only the number of moves.

Table II. Descriptive statistics, correlations between time and number of moves for each trial

Variables	*M*	*SD*	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1. MT : Time 1	83.47	43.52																
2. MT : Move 1	27.34	12.14	.76**															
3. MT : Time 2	53.61	34.47	.66**	.54**														

*p<.05, **p< .01, M = Mean, SD = Standard-Deviation, MT = Main Task, TT = Transfer Task

4. MT : Move 2	20.33	9.26	.63**	.58**	.90**												
5. MT : Time 3	32.95	22.01	.38**	.40**	.48**	.47**											
6. MT : Move 3	15.98	9.14	.38**	.39**	.45**	.51**	.85**										
7. MT : Time 4	28.49	20.83	.34**	.36**	.48**	.45**	.85**	.79**									
8. MT : Move 4	14.51	7.32	.39**	.35**	.53**	.54**	.78**	.82**	.90**								
9. TT : Time 1	70.04	32.88	.21*	.26**	.18	.24*	.43**	.45**	.35**	.40**							
10. TT : Move 1	28.17	12.32	.19*	.25**	.14	.21*	.37**	.40**	.32**	.42**	.83**						
11. TT : Time 2	44.93	25.19	.22*	.14	.24**	.29**	.33**	.44**	.36**	.43**	.63**	.61**					
12. TT : Move 2	17.92	8.83	.18	.13	.20*	.25**	.28**	.44**	.34**	.42**	.46**	.53**	.84**				
13. TT : Time 3	37.83	26.27	.35**	.39**	.41**	.43**	.42**	.45**	.36**	.35**	.44**	.40**	.58**	.51**			
14. TT : Move 3	17.07	11.35	.32**	.35**	.37**	.42**	.39**	.45**	.35**	.38**	.45**	.43**	.60**	.54**	.95**		
15. TT : Time 4	30.23	21.86	.28**	.42**	.29**	.39**	.33**	.38**	.29**	.30**	.40**	.37**	.50**	.47**	.79**	.81**	
16. TT : Move 4	14.06	8.70	.20**	.28**	.22*	.31**	.27**	.33**	.26**	.27**	.40**	.40**	.55**	.51**	.77**	.80**	.92**

Analysis of inhibition scores

The contribution of cognitive inhibition abilities to the performance in the transfer task was tested by multiple linear regression analyses on each transfer trial. In order to gain for statistical power, the transfer performance is the performance averaged out the 4 similarity conditions. The Day and Night test scores were not significantly associated with the number of moves in the trials of the main task except for the second trial (see Table III), but they were significantly associated with the number of moves in all transfer trials (significant trend for the first trial, see Table IV). The coefficients of the equations for trial 1 (b_1 = -.99, b_0 = 39.87), trial 2 (b_1 = -.93, b_0 = 28.87), trial 3 (b_1 = -1.91, b_0 = 39.51) and trial 4 (b_1 = -1.85, b_0 = 35.79) show that the better the cognitive inhibition abilities, the fewer the number of moves needed to perform the transfer task.

Table III. Predictive effect of inhibition on the number of moves on trials of the main task by multiple linear regression

	Bêta	R^2	R^2 ajusté	F	*p*
Trial 1	-.15	.02	.01	2.21	.14
Trial 2	-.21	.04	.04	4.68	.03
Trial 3	-.12	.02	.01	1.54	.22
Trial 4	-.14	.02	.01	1.86	.18

Table IV. Predictive effect of inhibition on the number of moves in transfer trials by multiple linear regression

	Bêta	R^2	R^2 ajusté	F	*p*
Trial 1	-.19	.04	.04	3.77	.055
Trial 2	-.25	.06	.05	6.60	.012
Trial 3	-.40	.16	.15	18.64	.001
Trial 4	-.50	.25	.24	33.49	.001

Discussion

The aim of this study was to test the hypothesis of a decrement in children's performance in a problem-solving task, and the role of tasks' and modalities' similarities as well as that of inhibition in resisting this decrement. A first hypothesis was that a decrement in performance would be observed between different versions of the Tower of Hanoi presented in different modalities (H1). In a second hypothesis, we predicted that performance in the transfer task would be higher in children in conditions with similar tasks' modalities (within-dimension conditions) compared to children in conditions with different tasks' modalities (cross-dimension conditions) (H2). In a third hypothesis, we predicted that children would show a rebound in performance on the second transfer trial (H3). Finally, we expected links between cognitive inhibition and transfer with a digital device, predicting a smaller decrement in performance in children who show high inhibition skills (H4).

Regarding our first hypothesis (H1), the results show that the number of moves required to solve the task increased from the fourth trial of the main task to the first trial of the transfer task, thus validating the hypothesis of a decrement in performance when switching from the main task to the transfer task. This result is consistent with those already obtained in previous studies on various knowledge domains using tangible tasks (Adi-Japha & Brestel, 2020; Clerc et al., 2013, 2021b; Detable & Vinter, 2006; Pacton et al., 2001; Resing et al., 2016), and also between two configurations of the ToH in digital versions (Schiff & Vakil, 2015). This result is interesting because several studies argue that the tablet has properties that would facilitate learning in children (Hirsh-Pasek et al., 2015; Major et al., 2017). In this sense, many studies have shown a beneficial effect of the touchscreen tablet on learning (see Haβler et al., 2016, for a meta-analysis), suggesting that the tablet would be a kind of "magical solution" against learning difficulties in children. If there is a beneficial effect of the touchscreen tablet on learning, it did not appear in this study. The results of our study show that digital transfer,

including a 2D/2D transfer situation, is accompanied by a decrement in performance. These results can be only interpreted in the context of the comparison between digital tasks on tablet and tangible tasks though, as we did not contrast the effect of the touchscreen tablet with another digital situation in which no haptic modality would be present, such as for example a transfer situation using video. Still, the decrement in performance at transfer seems to be explainable, in a 2D/2D digital transfer situation involving a touchscreen tablet, as in the case of transfer between tangible tasks, by the law of similarities (Klahr & Chen, 2011). Moreover, although it has been shown that transfer is more frequently observed in a near transfer situation (Aladé et al., 2016; Shipstead, Redick, & Engle, 2010), on closer inspection it is not always the case. Indeed, by looking separately at each trial of the transfer task, we found that when switching from the main task to the transfer task (e.g., in the first transfer trial), even in a near transfer situation a decrement in performance can be observed in children. Previous studies on the Tower of Hanoi in children suggest that the first phase of resolution consists of an exploration of the task in order to conceptualize the legal moves (Clément & Richard, 1997). On the first transfer trial, children may have explored the transfer task to determine if the legal moves to be applied are identical to those in the main task. Such exploration, linked to the task's changes, may have led the participants to produce erroneous moves, causing performance to decrease on the first trial at transfer. Moreover, there is no significant difference in the number of moves between the trial 1 in the main task and the trial 1 in the transfer task, both trials probably consisting of an exploration phase. In addition, individual profile analyses show that a decrement at transfer was widely observed, even in the children who solved the last trial of the main task with the optimal 7 moves procedure. This shows that these children who learned to perfectly solve the task along the four trials of the main task, were still concerned by the transfer decrement phenomenon. Indeed, they all exhibited a transfer decrement in the first transfer trial. This result sheds a new light on transfer in the

ToH task, suggesting that transfer decrement does not depend, or at least not solely, on mastering the optimal seven-moves procedure before transferring to a new task. This seems contradictory with the claim that initial deep understanding of the main task is likely to promote transfer (Chi & VanLehn, 2012). Given the implication of inhibition in transfer performance that was observed here, we suggest that the quality of transfer may also be explained by executive function. Previous research showed a beneficial role of inhibition on transfer (Clerc et al., 2014; Thibaut et al., 2011). This study confirms these results and extends them to a ToH task. Beyond, or in addition to, deeply understanding the main task, controlling the interferences caused by surface elements in the transfer task may play a pivotal role in the success of transfer (Thibaut et al., 2011). Future research should go a step further, by not only measuring individual levels of inhibition but experimentally varying the level of inhibition required in the transfer task, by varying the number of interfering elements to be controlled.

The literature on transfer often reflects on two cases of transfer: success or failure. The analyses of individual profiles in this study show that transfer in the ToH task does not always follow such an "all or nothing" pattern. In particular, transfer can alternate between decreasing and increasing performance in a same child. These results are consistent with those obtained by Chen and Klahr (1999), who showed that strategy transfer performance in problem solving in children does not always follow a linear pattern, sometimes showing irregular patterns of gain or lose in the use of a cognitive strategy.

Our results can also be explained within the framework of cognitive load theory. The cognitive load theory argues that cognitive load corresponds to the total quantity of cognitive resources allocated to the task to be solved (Sweller, 1994). A high cognitive load can be caused by multiple sources of information to process, which in turn can lead to a dissociation of attention (Sweller, 2005). In this study, the participants had to process multiple sources of

information. Solving the Tower of Hanoi involves perception-action coordination, which consumes many cognitive resources (Milla, Bakhshipour, Bodt, & Getchell, 2019). It requires the child to continually remember the rules, to plan the moves before executing them, which requires a significant cognitive effort for the child (Klahr & Robinson, 1981). In the transfer task, the children had to process the shape (disk), while maintaining the rules in their memory and at the same time planning the next moves. Moreover, because of its new surface features, the transfer task can be cognitively costly for a child, who must share his cognitive resources between processing the task by following the solving principle and accounting for the shape of the new stackable. This additional processing of the shape of the new stackable may have caused extrinsic cognitive load, known for hinder learning (Bellec & Tricot, 2013) and which appears to have decreased children's performance.

Our second hypothesis (H2) predicted better transfer performance in the two within-dimension conditions than in the two cross-dimension conditions. Although a decrement in performance is observed on the first transfer trial, children in the 2D/2D condition make significantly fewer moves than children in the two cross conditions. In contrast, their performance is not different from that of children in the 3D/3D condition, which only partially validates our hypothesis. In both cross-dimension conditions, the transfer task is presented in either a tangible or a touchscreen modality, depending on whether the main task is presented in one or the other modality. Indeed, according to Klahr and Chen's (2011) model, the probability of successful transfer is low when the tasks are dissimilar, as well as their respective contexts of presentation (far transfer). In this study, in both cross-dimension conditions, the surface dissimilarity between tasks was coupled with a dissimilarity between the tasks' modalities, with the tasks' modalities acting as the contexts of presentation of the two versions of the ToH (Barnett & Ceci, 2002; Moser et al., 2015). This joint dissimilarity of

tasks and modalities likely disrupted children far more in the cross-dimension conditions than in the 2D/2D condition, according to Klahr and Chen's (2011) model.

However, it is important to note that the two digital versions of the ToH are not totally comparable, since both contain different contextual elements. On the contrary, the two tangible versions are more similar to each other, with no contextual elements added from the main to the transfer task. The introduction of contextual elements in both digital versions aimed to make them resemble the usually presented items in many digital educative apps, and also to increase the need of control interference in these tasks. However, it may have made the comparison between the 2D/2D condition and 3D/3D condition somewhat unclear. Additional research is needed, which will strictly control for the same mapping, between the two digital tasks on the one hand and the two tangible tasks on the other hand, regarding the presence of different contextual elements from the main to the transfer task.

Consistent with cognitive load theory (Sweller, 1994), in addition to the new surface features, a change in transfer task' modality likely led to additional processing of the perceptual properties of the stackable in both cross-dimension conditions. This additional processing probably consumed some of the resources normally devoted to the essential cognitive load (Chanquoy, Tricot, & Sweller, 2007). A small amount of resources dedicated to the essential cognitive load does not allow for in-depth processing of the task, and in this case the structure of the transfer task. Moreover, a new task' modality constitutes new material to be processed, the mental integration and meaning of which are cognitively costly (Sweller, 2005). This would not have allowed children to allocate sufficient cognitive resources to process the structure of the transfer task and to detect the similarity with the main task, in order to effectively transfer the solving principle. For example, Zack et al. (2013) argued that the addition of specific linguistic cues in transfer task created additional processing and occasioned more cognitive load, thus interfering with transfer activity in children aged 15-16

months. The results obtained in our study extend those already observed in younger children, showing a decrement in performance when a change in modalities occurs (Moser et al., 2015; Zack et al., 2009, 2013).

Moreover, beyond the superiority of the within-dimension conditions over the cross-dimension conditions, the two cross-dimension conditions are themselves different from each other, regarding efficiency on transfer. On the second transfer trial, the performance of children who learned to solve the task in the touchscreen modality and transferred to the task presented in the tangible modality, differed significantly from those of children who learned to solve the task in the tangible modality and transferred to the touchscreen task. Thus, transfer of learning from touchscreen to tangible was better than from tangible to touchscreen.

Furthermore, the performance of children in the within-dimension conditions and that of children in the 2D/3D cross-dimension condition all differed from that of children in the 3D/2D cross-dimension condition. The latter condition was the one that allowed for the lowest transfer performance. This result is consistent with those of Huber et al. (2016) and Tarasuik et al. (2017). In these studies, in the main task, one group learned to solve the touchscreen version of ToH and another group learned to solve the tangible version. Then, both groups solved the tangible version in the transfer task. Both groups performed equally well on the transfer task, showing that the change in modalities did not prevent the children who learned to solve the touchscreen version from transferring efficiently. Nevertheless, as these studies did not study the quality of the transfer in the 3D/2D cross-dimension condition and did not vary the shape of the stackable, it was difficult to conclude on the effectiveness of the tablet on the performance in a ToH task. Thus, our study provides additional information on transfer of learning when it occurs between touchscreen and tangible versions of this task. It shows that when the shapes of the stackable are different between the two tasks, the transfer performance decreases. Nevertheless, this decrease is lower when the transfer occurs from a

touchscreen version to a tangible version than from a tangible version to a touchscreen version. The effectiveness of a touchscreen version of the ToH task has already been shown in previous studies in young adults, arguing that a tangible version consumes more cognitive resources than the digital version (Milla et al., 2019; Robinson & Brewer, 2016). Thus, touchscreen is far from being magic since transfer decrement is observed, but it seems to limit this decrement however. Because the tactile properties of the digital tablet allow for ease of use and interactive learning (Major et al., 2017), it provides an immersive experience and promotes engagement in a task (Hirsh-Pasek et al., 2015). This may explain its beneficial effect on learning and transfer, when compared to the tangible modality.

However, it is important to note that in our study, we did not use a baseline condition, in which the same task would have been presented twice with the same device (for example, presenting the same digital square version twice). This condition would have allowed us to see if the performance evolved differently, and in particular decreased on the 5th trial. In such a case, transfer decrement may have been explained by fatigue or lack of motivation at the beginning of the transfer task: thus, transfer decrement in our four conditions may also have been interpreted as being caused by fatigue or lack of motivation. Conversely, if in the baseline condition, performance would have been maintained or would have even increased at the 5th trial, we could have clearly eliminated fatigue or lack of motivation as a potential explanation for transfer decrement, which would have made our interpretation of the decrement in transfer performance in our four conditions clearer. The lack of a baseline condition constitutes a limitation in our study, that future research on transfer of learning between digital and tangible tasks must consider.

On the third and fourth transfer trials, there was no difference between the conditions, with all children performing equally well. One possible explanation is that, over the course of the trials, each group of children, depending on the condition in which they have learned to

perform the task, progressively acquired mastery of the task. This may gradually reduce the cognitive load, and hence make any difference in the performances between the groups disappear. Because transferring with a digital device requires the use of several cognitive entities (e.g., symbolic representation, encoding of perceptual properties of the material), it constrains the child's cognitive abilities and thus increases the cognitive load (Barr, 2013). However, the repetition of several trials is likely to help children deepen their understanding of the transfer task, which in turn lowers the amount of cognitive resources needed. Thus, although at the beginning of the transfer task there was a superiority of the touchscreen version of the ToH task, this superiority dissipated as children completed the transfer task. Future studies should seek to better understand this seemingly temporary superiority of the digital tablets in learning acquisition and transfer, as well as the contribution of context similarity (tasks' modalities), using other tasks than the ToH. This would provide answers about the value of using the tablet in school learning (Hirsh-Pasek et al., 2015; Mayer, 2016).

Our third hypothesis (H3) was that children should recover their performance over the course of the transfer task trials. The novelty of the surface features of the transfer task may have created uncertainties in the children, consuming some of the available cognitive resources and thus decreasing performance. Processing uncertainty is known to pose difficulties for children (Lyons & Ghetti, 2013). If this was the case, one would expect a rebound in performance by the second transfer trial. The results of our study show that children's performance re-increases between the first trial of the transfer task and the second trial. This performance improvement is maintained in the third trial and even increases in the fourth. Such a result may be explained by the dissipation of uncertainties over the course of the trials. On the first transfer trial, uncertainties may have led children to make erroneous moves that result in decreased performance. The first transfer trial probably served as an exploratory phase for the children. On the second trial, it is likely that, through metacognitive processes, the children

identified similarities with the main task, which may have led to efficient planning and execution of their moves, thereby increasing their performance at transfer (Clerc et al., 2014).

Over the course of the trials, by solving the same task repeatedly, it is also possible that the cognitive load related to the task demands decreased. For example, Milla et al. (2019) showed in young adults, that as they solved variants of the ToH task, a decrement in effort was observed, evidenced by more efficient use of neural resources. In our study, it could be that on the second and third transfer trials, children learned to plan their actions better, and that on the fourth trial, they used less resources to plan the actions, thus allocating more resources to their execution and thereby increasing their performances.

Our final hypothesis (H4) addressed the contribution of cognitive inhibition to transfer with a digital tablet. Regression analyses showed a relationship between cognitive inhibition and transfer performance. The better the inhibition skills, the fewer the number of moves needed to perform the transfer task, which validates the hypothesis. Results show that the inhibition scores did not predict children's performance on the main task. Richard, Clément, and Tijus (2002) argue that during the first phase of solving a problem such as the Tower of Hanoi, solvers learn the rules and discover legal moves. The present study suggests that in the digital transfer paradigm between two versions of the Tower of Hanoi, children indeed probably learn the rules and discover the legal moves on the first trial of the main task. On subsequent trials, they likely engaged in the main task without exercising a high degree of control over their cognitive processes. Nevertheless, a relationship between inhibition scores and the number of moves on the second trial of the main task was observed. This link is maybe due to the many failures seen in the first trial. On the first trial of the main task, children possibly engaged in the task, without controlling themselves, and even more so with the touchscreen tasks. Thus, having probably noticed the difficulty of the task, on the second trial they controlled themselves. In view of the non-significant links between inhibition and the

following trials of the main task, it is likely that the children, after having controlled themselves on the second trial, have automated the solving principle. This would explain why inhibition is not involved in the solving of these trials 3 and 4 in the main task. Although this explanation is somewhat speculative, we think that it may apply to the results. Indeed, even if we did not measure children's engagement in the tasks presented on the touchscreen modality, it is known that digital tablets foster child' engagement in the task. Future research should examine this hypothesis in a more systematic way.

In contrast, in the transfer task on the first trial of the transfer task, rather than relearning the rules and legal moves, it is likely that children learn to inhibit interference caused by dissimilarities in tasks and/or task'modality. This is consistent with the results of this study, which show that inhibition predicts performance on transfer trials. Indeed, although on the first trial there was only a trendy relationship, inhibition scores significantly predicted the number of moves in all other trials. Thus, it appears that cognitive inhibition played a role in children's performance in the transfer task. The model proposed by Richard, Poitrenaud, and Tijus (1993) argues that solving the ToH involves a cognitive conflict between implicit constraints imposed by the solver, and explicit constraints imposed by the task. The solver must solve this cognitive conflict to perform the task efficiently, especially through inhibiting the illegal moves that the solver can afford when he is in a deadlock situation due to the various implicit constraints. It is also possible that this conflict, inherent to the ToH task, was accentuated by the dissimilarity between the shape of the stackable (squares vs disks) and between the type of locations (planks vs pegs). All the information processed in working memory probably disrupted the children's understanding of the transfer task, which is essential for the completion of the task. To process the transfer task, it was necessary to inhibit inappropriate information, especially the perceptual properties of the stackable. Studies have shown that the activation of the heuristic system over the algorithmic system, which is

nonetheless appropriate in the processing of reasoning and problem-solving tasks in children, is due to a failure to inhibit heuristics (Lubin et al., 2013; Houdé & Guichart, 2001).

In addition, for participants in the cross-dimension conditions, interferences due to the dissimilarity of the tasks' modalities occurred, causing additional processing. This constitutes a source of specific irrelevant task features, that children had to inhibit. Thus, children had to inhibit much information at different levels, according to Diamond's (2013) model. Presumably, children who were more able to efficiently inhibit this flow of information were able to allocate more resources to the processing of the transfer task's structure, and thereby transferred the solving procedure more efficiently. Such results suggest that cognitive inhibition is involved in the transfer of learning when it includes a digital device. However, it is difficult to conclude firmly on the causal role of inhibition because of the experimental design used and the analyses performed. Further research needs to be conducted, which would directly test the causal involvement of inhibition in the transfer with digital device.

Finally, the results obtained in our study show that the phenomenon of decrement in transfer performance can be also observed in children performing the ToH presented on a digital tablet. It seems that the digital and tangible versions of the ToH require common cognitive processes, which would be responsible for this decrement in transfer in problem- solving. Such a decrement has been reported many times in the literature (Adi-Japha & Brestel, 2020; Clerc et al., 2013; Chen & Klahr, 1999; Pacton et al., 2001; Resing et al., 2016). Nevertheless, the decrement in transfer was less pronounced for children in the within-dimension conditions, and even more so for children in the 2D/2D condition. Thus, even if we observed a decrement in transfer performance in digital transfer, 2D/2D condition still seems to be the best combination to face this decrement. Indeed, properties of the digital tablet allows for engagement in the task (Robinson & Brewer, 2016), which promotes deep learning. Furthermore, when the main task and the transfer task used the same tasks'modality, it is

likely that the transfer task was less cognitively costly. Engagement and lower cognitive cost may explain why the decrement in transfer performance was less pronounced in the 2D/2D condition. This also implies that when the tasks are similar and their contexts are similar too, children are more resistant to the decrement of performance in the transfer task (Klahr & Chen, 2011).

In addition, we also conducted a cluster analyse that showed different learning and transfer profiles. According to this analysis, we cannot conclude unequivocally about context effects. Indeed, it seems that independently of the similarity of modalities, different transfer profiles are observed. This shows that individual profiles could partly explain transfer performance. Nevertheless, the Anova showed that the modality partly explains the quality of the transfer performance.

Furthermore, we examined near and far transfer situations, by operationalizing the context through tasks' modalities. Thus, we varied the tasks and their modalities, but this design did not allow us to directly test the Klahr and Chen's (2011) model. Indeed, while we were able to create context similarity (2D/2D and 3D/3D) and context dissimilarity (2D/3D and 3D/2D) conditions, we were not able to create the other transfer situations described in Klahr and Chen's (2011) model: strong task similarity and strong context similarity, strong task similarity and weak context similarity, and weak task similarity and weak context similarity. A digital device can represent multiple learning contexts, in the sense of more or less seductive details surrounding the task presented on the screen. Varying the amount of such details would allow to vary both the degree of similarity of the tasks themselves and of their digital contexts of presentation. Future studies should be devoted to this question.

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