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## Young children's transfer of learning on a touchscreen tablet is determined by similarities between tasks and between digital contexts

Wilfried T. Mombo<sup>a,\*</sup>, Laureen Josseron<sup>a</sup>, Jean-Charles Quinton<sup>b</sup>, Jerome Clerc<sup>a,\*\*</sup>

<sup>a</sup> Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LPNC, 38000, Grenoble, France

<sup>b</sup> Univ. Grenoble Alpes, CNRS, Grenoble INP, LJK, 38000, Grenoble, France

### A B S T R A C T

Transfer of learning is influenced by transfer distance, i.e., the degree of correspondence of contexts as well as of the content to be transferred between a main task and a transfer task (Barnett & Ceci, 2002; Klahr & Chen, 2011). A long tradition of research has used either similarity of tasks or similarity of contexts designs to test transfer distance in problem-solving in children. To our knowledge, no study to date has experimentally varied the degree of similarities between tasks and between contexts jointly, which is the aim of this study. In the present study, we varied the degree of similarity between tasks, by presenting different versions of the Tower of Hanoi (ToH), and between digital learning contexts, by presenting different graphical interfaces. One hundred children aged 6 to 7 years old were divided into four conditions, High similarity of tasks/High similarity of contexts (H/H); High similarity of tasks/Low similarity of contexts (H/L); Low similarity of tasks/High similarity of contexts (L/H); Low similarity of tasks/Low similarity of contexts (L/L). Inhibitory control was also measured, as it may be involved in transfer of learning (Clerc, Miller, & Cosnefroy, 2014; Thibaut, French, Vezneva, Gérard, & Glady, 2011). Transfer of the solving procedure was accompanied by a performance decrement in the L/L and H/L conditions, whereas no such decrement was observed in the L/H and H/H conditions, showing the role of the similarity of digital contexts. Furthermore, inhibition scores predicted transfer performance. Results are discussed considering the theoretical framework of similarities between tasks and between contexts, and the role of inhibition.

### 1. Introduction

Transfer of learning consists of reusing some knowledge acquired in a first task, namely the main task, in a new task, namely the transfer task (Cox, 1997; Helsdingen, van Gog, & van Merriënboer, 2011). It is core in children's development, enabling them to adapt to new situations based on previous knowledge. Spontaneous transfer of learning is difficult to elicit in children (Day & Goldstone, 2012; Siegler, 2006), and in instances where successful transfer is observed, performance level in the transfer task is still frequently lower than that of the learning task (Perruchet & Vinter, 2002). The difficulty of transferring learning is often explained within the theoretical framework of similarity of tasks and similarity of contexts. The probability of successful transfer is high when the main task and the transfer task are similar, as are their respective presentation contexts, but when differences between tasks and contexts become more pronounced, transfer becomes harder (Klahr & Chen, 2011). Despite the existence of this theoretical framework and to our knowledge, no study did experimentally vary the similarity of tasks and the similarity of contexts jointly. Yet, this may provide

detailed information about children's transfer abilities when different features of the main and transfer tasks, as well as their respective presentation contexts, vary at the same time.

Difficulty in transferring learning is even more of a problem for children with the emergence of digital devices. Indeed, there is a growing development of educational applications, that would enable children to learn on digital devices used both at school and at home (Hirsh-Pasek et al., 2015). Digital devices are indeed frequently involved in children's daily activities, including learning. They constitute genuine learning tools, and what is learned through a digital task may potentially be transferred to another digital task. For these reasons, we need to understand the mechanisms that determine the transfer of learning when it occurs in digital devices. The aim of this study is therefore to investigate the contribution of both similarity between tasks and similarity between their contexts of presentation in the occurrence of transfer with digital devices, which to our knowledge has not yet been studied experimentally.

\* Corresponding author. Univ. Grenoble Alpes, Univ. Savoie Mont Blanc, CNRS, LPNC, 38000, Grenoble, France.

\*\* Corresponding author.

E-mail addresses: [wilfried.mombo@univ-grenoble-alpes.fr](mailto:wilfried.mombo@univ-grenoble-alpes.fr), [wilfried.mombo@univ-tours.fr](mailto:wilfried.mombo@univ-tours.fr) (W.T. Mombo), [laureen.josseron@univ-grenoble-alpes.fr](mailto:laureen.josseron@univ-grenoble-alpes.fr) (L. Josseron), [quintonj@univ-grenoble-alpes.fr](mailto:quintonj@univ-grenoble-alpes.fr) (J.-C. Quinton), [jerome.clerc@univ-grenoble-alpes.fr](mailto:jerome.clerc@univ-grenoble-alpes.fr) (J. Clerc).

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## 1.1. Transfer of learning

### 1.1.1. The laws of similarities: The model of Klahr and Chen (2011)

Drawing on a long tradition of research into analogical transfer and transfer of training, Barnett and Ceci (2002) reported that studies of analogical transfer have often yielded mixed results, with transfer successes and failures. To explain these mixed results, Barnett and Ceci (2002) proposed a taxonomy of transfer, based on transfer distance, i.e., the degree of correspondence of contexts as well as of the content to be transferred between a main task and a transfer task. Transfer distance implies that, as differences between the main task and the transfer task and between the learning context and the transfer context increase, performance at transfer gradually decreases. A near transfer situation is therefore defined as a situation including only small differences between the context and/or content of the main task and the context and/or content of the transfer task. A far transfer situation is defined as a situation including larger differences in context and/or content between the main task and the transfer task (Moser et al., 2015). Furthermore, the near vs far transfer theoretical framework should be understood as a continuum rather than as purely dichotomic.

Barnett and Ceci's (2002) taxonomy is supported by Klahr and Chen (2011), who have proposed a conceptual model of transfer, based on the degree of similarity between tasks and the degree of similarity between contexts. According to this model, a transfer situation implies three dimensions: tasks' similarity, contexts' similarity, and temporal interval. Tasks' similarity refers to the common features shared by the main task and the transfer task such as knowledge domain (mathematics, physics, etc.), materials used (text, picture, etc.), procedures, and resolution principles. The degree of tasks' similarity is defined by the alignment between the structure elements and the surface elements between both tasks. The structure elements of a task are directly relevant to solve this task, as for example the legal operators in the Tower of Hanoi (ToH) task. In contrast, the surface elements refer to the salient "covering" of the task (e.g., the statement of a story, Corbalan, Kester, & Van Merriënboer, 2011; Gick & Holyoak, 1987), including perceptual features (e.g., color of the visually presented items, Thibaut, French, & Vezneva, 2010). Those surface elements can vary between several versions of a task which nevertheless share the same structure. Using perceptual features constitute a fine test of the role of surface similarities in transfer, especially in the decrement of performance which sometimes occurs in transfer. Thibaut et al. (2010) have shown that 6-year-olds have difficulty solving perceptual problems involving color analogies when the analogical stimulus, i.e., the same color, is presented with a distractor stimulus, i.e., the same shape but a different color. The authors argue that children actively build on the perceptual features of the stimuli to determine similarities. Perceptual changes are therefore sufficient to distinguish between two tasks, considering such two tasks as a main task and a transfer task.

Contexts' similarity refers to the features that the context of the main task and the context of the transfer task share. Following Barnett and Ceci (2002), it concerns the environment in which a task is embedded, including people, building, and locations. Moreover, the screen of a digital device allows for modifications of the visual digital environment surrounding a task, by adding or removing different components to obtain a given digital context. The definition of contexts' similarity is thus enriched in the digital age by the existence of digital contexts of transfer of learning.

A third dimension of transfer is the temporal interval, which refers to the time gap elapsed between the main task and the transfer task. The time gap can range from minutes to decades, and a gap that is too large can make the performance decrease. The model of Klahr and Chen (2011) predicts that the higher probability of successful transfer is associated with high similarity of tasks, high similarity of contexts, and a short time interval.

Manipulating the degree of similarity between tasks and between their presentation contexts shows under which conditions transfer

performance declines. Studies in children have shown that, when the content between the main task and the transfer task change (e.g., measuring a giraffe, then measuring a robot, Aladé, Lauricella, Beaudoin-Ryan, & Wartella, 2016), or when the presentation modalities change from one task to another (e.g., 2D vs. 3D, Moser et al., 2015; Zack, Barr, Gerhardtstein, Dickerson, & Meltzoff, 2009), transfer is accompanied by a decrement in performance. However, these studies showed that a decrement in transfer performance occurs when tasks change or when their modalities change, but did not inform about the effectiveness of children's transfer when both tasks and contexts change. Yet, such information may provide a better understanding of the influence of task similarity and context similarity on transfer completion, especially when tasks and contexts differ simultaneously. This is what we aimed to investigate in the present study.

### 1.1.2. Decrement in transfer performance with digital devices: the case of the Tower of Hanoi (ToH)

The Tower of Hanoi (ToH) task allows for the examination of cognitive procedural learning (Beaunieux et al., 2006). To study the transfer of previously learned cognitive procedures, it is relevant to use different versions of the ToH, as was done in several recent studies (Huber et al., 2016; Mombo & Clerc, 2022; Schiff & Vakil, 2015; Tarasuik, Demaria, & Kaufman, 2017). These studies yielded mixed results, probably due to their experimental designs. Indeed, in the study by Schiff and Vakil (2015), the performance of 8-year-old children declined when they were instructed to solve a second variant of the ToH by moving the disks from the left to the right, rather than from the right to the left as in the first variant. Such a change in the direction of moves likely led to a change in the abstract representation of the task, preventing the children from using the previously constructed procedure and thus lowering their performance. In studies by Huber et al. (2016) and Tarasuik et al. (2017), 6-year-olds practiced solving a digital version (2D) of the ToH and transferred the procedure to an isomorphic tangible version (3D). In such a design, although there was a difference in the modalities of the tasks, and therefore a surface difference between tasks, the aim of the transfer task did not change from those of the main task. Practicing the task in a digital version first, and the identical aim shared by the digital and the tangible version of the task, certainly enabled the children to maintain their performance in the transfer task. In a recent study in 6-year-old children, Mombo and Clerc (2022) widened the differences between tasks, by varying the modalities of the tasks (2D vs 3D) and also the shapes of the stackable pieces (disks vs squares). An overall decrement in performance when transferring the cognitive procedure from a digital to a tangible version of the ToH task was observed, implying that when differences between tasks become wider, children's performance gradually decreases. Furthermore, different individual patterns of performance decrease in the transfer task were observed. Depending on the participants, the performance in the transfer task either alternated between decrease and increase over the course of the trials. Such results show that transfer in the ToH task does not always follow an all-or-nothing pattern, which is consistent with studies showing that transfer trials can alternate between failure and success in a single child (Chen & Klahr, 1999). Studying the temporal dynamics of transfer performance seems thus required, which may be achieved through trial-by-trial analyses.

Trial-by-trial analyses should make it possible to observe in detail the decrement in performance, especially the one which can be observed when an individual switches from the last trial of a main task to the first trial of the transfer task (Schiff & Vakil, 2015). Furthermore, it should allow us to observe whether this decrement at the first transfer trial is followed by a recovery in performance on the next trial. Last, trial-by-trial analyses are scarce in the transfer literature, despite recommendations for measuring transfer in multiple ways to gain a more comprehensive view of it (Nokes, 2009). A performance decrease at transfer is by no way trivial, and more studies are needed to explain it which would benefit from trial-by-trial analyses.

Decrement in transfer and the reasons for it remain mixed. As was proposed by Klahr and Chen (2011), the similarity of contexts is as important as the similarity of tasks in predicting transfer. Yet, for many decades, transfer has been measured almost exclusively based on the similarities of tasks, the contextual dimension being largely ignored. The impact of similarity of contexts on the adaptation of knowledge to the transfer task is thus still to be analyzed. A digital device, like for example a digital tablet, can contain many different digital learning contexts which can be linked to the same given task presented on the screen. Manipulating several contexts for the same task is thus made easy with a digital tablet, and may advance our understanding of the impact of context in the occurrence of decrement in transfer performance.

### 1.2. Graphical interface as a learning context

A graphical interface is the arrangement of icons, pictograms, and pictures on a screen. It is intended to allow for intuitive discovery of actions. Therefore, it is necessary to address how to present learning content in a way that initiates appropriate cognitive processing during learning (Mayer, 2008; Moreno, 2006). Some elements of a scenery that surround the task within the screen, so-called seductive details, can be used to brighten children's mood, motivating them and maintaining their engagement throughout the learning activity (Moreno, 2005, 2006). However, when they are irrelevant to the learning activity *per se*, seductive details are likely to interfere with performance (Wang & Adesope, 2014).

In children, interacting with the graphical interface is more likely to occur using a digital tablet than any other devices (PC, touchscreen display), as a tablet is more accessible to them (Major, Haßler, & Hennessy, 2017). Furthermore, as mentioned above, the graphical interface of a digital tablet can be considered as a digital learning context. Indeed, considering that a task can be presented at the same time as the seductive details, the latter can be considered as contextual elements, and can vary. This leads to reconsider transfer of learning in the digital age, since the task and its context are somewhat merged on the screen, contrary to what happens in tangible transfer situations where contextual elements are more clearly distinguished from the task (Barnett & Ceci, 2002). Thus, a digital learning context refers to the visual perceptual elements that surround the task within the screen, including, but not limited to, seductive details.

Finally, given that any transfer situation includes a new task (e.g., the transfer task), as well as a new context (e.g., context of presentation of the transfer task), and requires adaptation to it (Schwartz, Chase, & Bransford, 2012), Executive Functions (EF) may be involved.

### 1.3. Inhibition in transfer of learning

To adapt to non-routine situations, the individual calls upon his or her EF. EF are a set of high-level cognitive processes whose role is to facilitate adaptation (Diamond, 2020). Moreover, the need to control for surface elements of the transfer task, which are not relevant to transfer the structure of the main task but cannot be ignored, makes inhibitory control most likely. Diamond (2013) argues that inhibitory control has two aspects. The first is response inhibition, which involves controlling one's motor behavior and emotions. The second aspect is interference control, which consists of resisting extraneous or unwanted thoughts by maintaining them at a distance from working memory. Interference control is thus provided by cognitive inhibition, and it may be implied in the performance decrement frequently observed in transfer of learning (Clerc et al., 2014).

Furthermore, in digital tasks, not only the tasks themselves can vary in their components, but their digital contexts can also vary. As mentioned above, the addition of scenery elements on the graphical interface (seductive details) can disrupt learning, and they are likely to disrupt transfer if they are not present in the main task. Controlling for the interferences caused by such seductive details in a transfer task

seems necessary to achieve successful transfer. Interference control applied to both tasks dis-similarities and contexts dis-similarities seems thus necessary to achieve transfer.

### 1.4. Present study

A growing developmental literature on transfer uses within-dimensional (2D/2D and 3D/3D) and cross-dimensional (2D/3D and 3D/2D) experimental designs, to study transfer between tasks presented with the same or different modalities, which is consistent with the theoretical framework of similarity of tasks and similarity of contexts (Huber et al., 2016; Mombo & Clerc, 2022; Moser et al., 2015; Tarasuik et al., 2017; Zack et al., 2009). Nevertheless, to date, this design has not been used to investigate the other transfer situations described in the model of Klahr and Chen (2011), i.e., high similarity of task and high similarity of context; high similarity of task and low similarity of context; low similarity of task and low similarity of context. Thus, in the current study, we were interested in the contribution of the degrees of similarity between tasks and similarity between their contexts of presentation, in the progressive onset of decrement in transfer performance. For this, we varied the degrees of similarity between the tasks and between the contexts, by considering the shapes of stackable pieces as surface features of tasks and a tablet graphical interface as a digital learning context. This is a new way of dealing with the issue of context, allowing us to study finely, in an experimental setting, the joint similarity between tasks and between contexts.

We hypothesized a decrement in transfer performance between different digital versions of the ToH (isomorphic tasks) characterized by both surface dis-similarities and context dis-similarities, which constitutes a low degree of similarities (H1). This decrement in performance should be reduced between versions with either context dis-similarities but surface similarities, or surface dis-similarities but context similarities which constitutes an intermediate degree of similarities (H2). We also expected this performance decrement to be further absent between versions presenting both surface and context similarities, which constitute a high degree of similarities (H3). Furthermore, we predicted that the decrement in the transfer task would be temporary, with children's performance rebounding as the child progressively adapts to the new task through the successive transfer trials (H4). Finally, because a lack of inhibition has been suggested as a potential cause of transfer difficulties in children (Clerc et al., 2014), we wanted to investigate the role of individual capacity of inhibition in resisting the decrement in transfer performance. For this reason, the decrement in transfer performance can be expected to be higher in children with lower inhibition skills (H5).

## 2. Method

### 2.1. Participants

A power analysis using G\*Power 3.1 software (Faul, Erdfelder, Buchner, & Lang, 2009) indicated that a total sample of ninety-six participants would be needed to detect a medium effect size 0.25, with a statistical power of .80 and an alpha level of 0.05, using a *F* test (A mixed Anova). One hundred children ( $M_{age} = 6.8$  years,  $SD_{age} = 0.54$ ; 62 girls) recruited from an elementary school in Grenoble (France), participated in this study. According to the information provided by parents and teachers, none of the children showed any signs of atypical development or cognitive or learning disorders. The study received a favourable opinion from the Grenoble Alpes Research Ethics Committee.

### 2.2. Material

#### 2.2.1. Task

The task used in this study is the three stackable pieces ToH. In this task, an original pattern of three disks is presented, with a small disk

being placed on a medium one, which is placed on a large one. All three are threaded on a peg, at the left, and the apparatus contains two other pegs placed to its right. The participant must reproduce the original pattern on the extreme right peg by moving the disks on the pegs, following two rules: no more than one disk can be moved at a time, and one can only put a disk onto a larger disk or on an empty location. In this study, the task was to be performed by sliding the finger on the touchscreen. The ToH task needs at least seven moves to be correctly performed. We used three versions: one with three disks, one with three rectangles and, one with three trapezoids. These three versions were presented in three different counterbalanced digital contexts (graphical interfaces), which we varied according to the different conditions of the experiment: context 1 contained coconut trees, bumpy sand and pebbles, the sea and the sun; context 2 contained shrubs, bumpy greenery and a sky in the background; context 3 contained a city and a cloudy sky.

Tasks were presented on an application developed for the purpose of this study and were performed on an acer Iconia One 10 B3-A40-K2AM 10.1 touchscreen tablet, with a screen size of 10.1", a resolution of 1280x800px, a length of 258 mm, a width of 167.5 mm and a height of 9.15 mm.

### 2.2.2. HTKS inhibition test (Ponitz, McClelland, Matthews, & Morrison, 2009)

Because participants in this study were French children, a French version of the Head, Toes, Knees, Shoulders test ("HTKS", Ponitz et al., 2009) was used to test inhibitory control through the inhibition of behavioral motor responses (Diamond, 2013). This is consistent with the ToH task, whose realization commands motor moves. HTKS inhibition test requires the child to produce a motor response following a verbal command from the experimenter. The participant must touch a different body part than the one indicated, for example, touch their head when they are told to touch their toes and vice versa. The task comprises three phases: head and toes (phase 1), shoulders and knees (phase 2), head/knees and shoulders/toes (phase 3). Each phase consists of ten items and each item scores 2 points (correct answer), 1 point (self-corrected answer) or 0 point (incorrect answer). The maximum score is therefore 60 points, a high score indicating a high capacity of inhibition.

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

The Day and Night inhibition test (Gerstadt et al., 1994) is a prepotent response suppression test used to evaluate interference control in children (Diamond, 2013). It contains two types of paper cards, representing either the moon or the sun. 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 of cognitive inhibition. 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 (Simpson et al., 2012; Simpson & Riggs, 2005; Thibaut et al., 2011).

## 2.3. Experimental design

Children were randomly assigned to one out of four experimental

conditions defined by low vs. high degrees of similarity of tasks and low vs. high degrees of similarity of contexts. The low vs high degrees of similarity of tasks were obtained by varying the perceptual features of the stackable pieces (e.g., rectangular, trapezoid, and disk, see Fig. 1). Low perceptual similarity of tasks concerns stackable pieces whose shapes differ (e.g., rectangle vs. disk); high perceptual similarity of tasks concerns stackable pieces whose shapes are very close (e.g., rectangle and trapezoid). Low vs. high degrees of similarity of contexts were obtained by varying the seductive details. Low degree of similarity of contexts concerns seductive details which are semantically distant (e.g., coconut trees vs. house); high degree of similarity of contexts concerns seductive details which are semantically more similar (coconut trees and shrub). Thus, the degree of similarity of the digital contexts lies on a semantic dimension.

The four experimental conditions are:

- High similarity of tasks and High similarity of contexts (H/H). Main task: ToH with three rectangles, context 1 (coconut trees). Transfer task: ToH with three trapezoids, context 2 (shrubs).
- High similarity of tasks and Low similarity of contexts (H/L). Main task: ToH with three rectangles, context 1 (coconut trees). Transfer task: ToH with three trapezoids, context 3 (houses).
- Low similarity of tasks and High similarity of contexts (L/H). Main task: ToH with three rectangles, context 1 (coconut trees). Transfer task: ToH with three disks, context 2 (shrubs).
- Low similarity of tasks and Low similarity of contexts (L/L). Main task: ToH with three rectangles, context 1 (coconut trees). Transfer task: ToH with three disks, context 3 (houses).

## 2.4. Procedure

All children were met individually in their school during school hours. The participant was seated in a chair, with a table in front of him/her on which the digital tablet was placed. The experimenter sat in a chair to the right of the participant. The study was conducted in three phases: a learning phase (main task), a transfer phase (transfer task), and a final phase devoted to the evaluation of capacity of inhibition.

### 2.4.1. Main task

This phase was held in the morning. 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 stackable piece at a time", the experimenter then moved the small stackable piece to the right location); then a forbidden move ("You cannot put a large stackable piece on top of a smaller one", the experimenter then moved the medium stackable piece 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. Feedback was provided by the tablet to the participant each time participant broke a rule (the stackable piece was automatically returned to its previous location), along with an explanation from the experimenter (e.g., "the stackable piece is returned because you cannot put a large stackable piece on top of a smaller one"). The participant then had to perform four trials on his own, in one go. There was no time limit, the trial ended when the task was solved.

### 2.4.2. Transfer task

To limit the cognitive fatigue that could be generated by the successive resolution of too many trials, children performed this task after a lunch break. Also, this temporal interval between the main and the transfer task was the same for all children, controlling for time gap. This method has previously been used in near transfer of memory strategies studies (Clerc & Miller, 2013; Clerc, Leclercq, Paik, & Miller, 2021) and allowed to measure the performance decrease in the transfer task. The

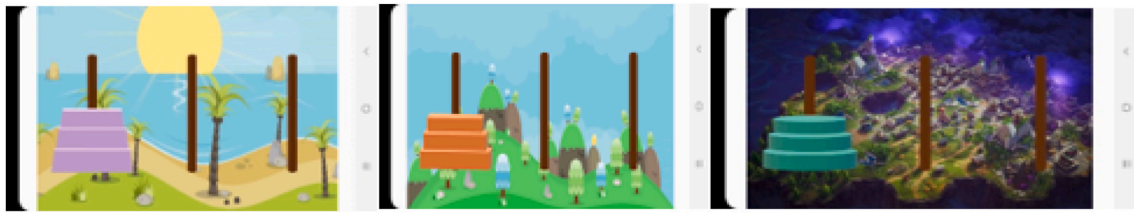


Fig. 1. Screenshot of the three versions of the digital Tower of Hanoi presented in the three digital contexts. From left to right: the trapezoids presented in the “coconut trees” context, the rectangles presented in the “shrubs” context, and the disks presented in the “houses” context.

task was performed without reference to the main task. The experimenter explained the rules to the child, but if the child broke a rule, the stackable piece 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 co-performed trial and the explanation provided to the participant during the main task, the transfer trials were performed with the same formalities as the learning trials (rules, feedback “return the stackable piece to the original location in case of error”, no break between the trials, no time limit). The day after, participants had to perform the two inhibition tests. HTKS was administered in the morning and all three phases of this test were administered at once, without a break. The Day and Night test was administered in the afternoon.

2.5. Measurement

For all versions of the ToH, we measured the total number of moves required to solve the task, corresponding to all action sequences performed for its completion. It illustrates the cognitive procedure used by children to solve the problem.

3. Results

3.1. Transfer analysis of number of moves

A mixed Anova 2 (task, within-subjects) × 4 (trial, within-subjects) × 4 (degree of similarity, between-subjects) was conducted on the total number of moves performed (Table 1).

The main effect of trial was significant,  $F(3, 214) = 4.60, p < .001, \eta^2p = .05$ . Performance increased from trial 1 ( $M = 19.6, SD = 8.56$ ) to trial 2 ( $M = 16.4, SD = 6.69$ ),  $p < .001$ , from trial 2 to trial 3 ( $M = 12.6, SD = 3.87$ ),  $p < .001$ , and held from trial 3 to trial 4 ( $M = 12, SD = 4.49$ ),  $p = .52$ .

The task × degree of similarity interaction effect was significant,  $F(3, 95) = 4.54, p < .001, \eta^2p = .15$ . Pairwise comparisons between the degrees of similarity were performed for each task. In the main task, there was no significant difference between conditions. Of particular interest is that in the transfer task, Bonferroni corrected post-hoc tests

revealed that the children in the High similarity of tasks/High similarity of contexts condition ( $M = 12, SD = 3.85$ ) outperformed children in the Low similarity of tasks/Low similarity of contexts condition ( $M = 17, SD = 6.08$ ),  $p = .02$ , as well as children in the High similarity of tasks/Low similarity of contexts condition ( $M = 16.6, SD = 5.25$ ),  $p = .03$ .

The task × trial × degree of similarity interaction was significant,  $F(7, 237) = 5.63, p < .001, \eta^2p = .15$ . We tested the hypothesis of a decrement in transfer performance in the four degree of similarity conditions. For this, in each condition we conducted pairwise comparisons with the Bonferroni test correction between trial 4 of the main task and trial 1 of the transfer task. Then, similar analyses were conducted between trials 1, 2, 3 and 4 of the transfer task to test the hypothesis of performance recovery, leading to 4 comparisons in each condition. In the High similarity of tasks/High similarity of contexts (H/H) condition, there was no significant difference between the fourth trial of the main task ( $M = 12.6, SD = 6.03$ ) and the first trial of the transfer task ( $M = 12.5, SD = 4.69$ ). There was also no significant difference between any transfer trials when compared with each other, attesting to an absence of decrement in transfer performance and a maintenance of performance over trials in this H/H condition. Likewise, in the Low similarity of tasks/High similarity of contexts (L/H) condition, there was no significant difference between the fourth trial of the main task ( $M = 11.8, SD = 4.00$ ) and the first trial of the transfer task ( $M = 18.00, SD = 10.74$ ). There was also no significant difference between transfer trials compared with each other, showing an absence of decrement in transfer performance in this L/H condition. In contrast, in the High similarity of tasks/Low similarity of contexts (H/L) condition, children performed the fourth trial of the main task ( $M = 11, SD = 4.34$ ) in a significantly lower number of moves than the first trial of the transfer task ( $M = 23, SD = 10$ ),  $p = .008$ , attesting to a decrement in performance at transfer. When compared with each other, there were no significant differences between the transfer trials, attesting to an absence of performance recovery along the transfer trials. In the Low similarity of tasks/Low similarity of contexts (L/L) condition, children performed the fourth trial of the main task ( $M = 13.5, SD = 6.19$ ) in a significantly lower number of moves than the first trial of the transfer task ( $M = 24.9, SD = 15.46$ ),  $p = .003$ , thereby showing a decrement at transfer. When the transfer trials were compared with each other, the results showed that

Table 1 Means and Standard Deviations for the number of moves, in each condition of degree of similarity and in both main and transfer tasks’ trials.

Trials	Main Task M(SD)				Transfer Task M(SD)			
	1	2	3	4	1	2	3	4
L/L	17.2(8.51)	15.8(7.27)	15.1(6.81)	13.5(6.19)	24.9(15.46)	19.3(9.54)	11.9(4.48)	12.0(4.53)
L/H	19.4(9.94)	18.6(12.14)	13.0(6.33)	11.8(4.00)	18.0(10.74)	14.8(8.83)	11.7(4.82)	10.1(3.72)
H/L	21.1(9.73)	16.7(7.44)	12.8(6.78)	10.9(4.20)	22.5(10.03)	17.4(7.87)	13.8(4.95)	13.4(7.77)
H/H	21.6(9.66)	17.2(7.82)	11.5(3.5)	12.6(6.03)	12.5(4.69)	12.2(6.00)	11.4(3.44)	11.8(7.23)

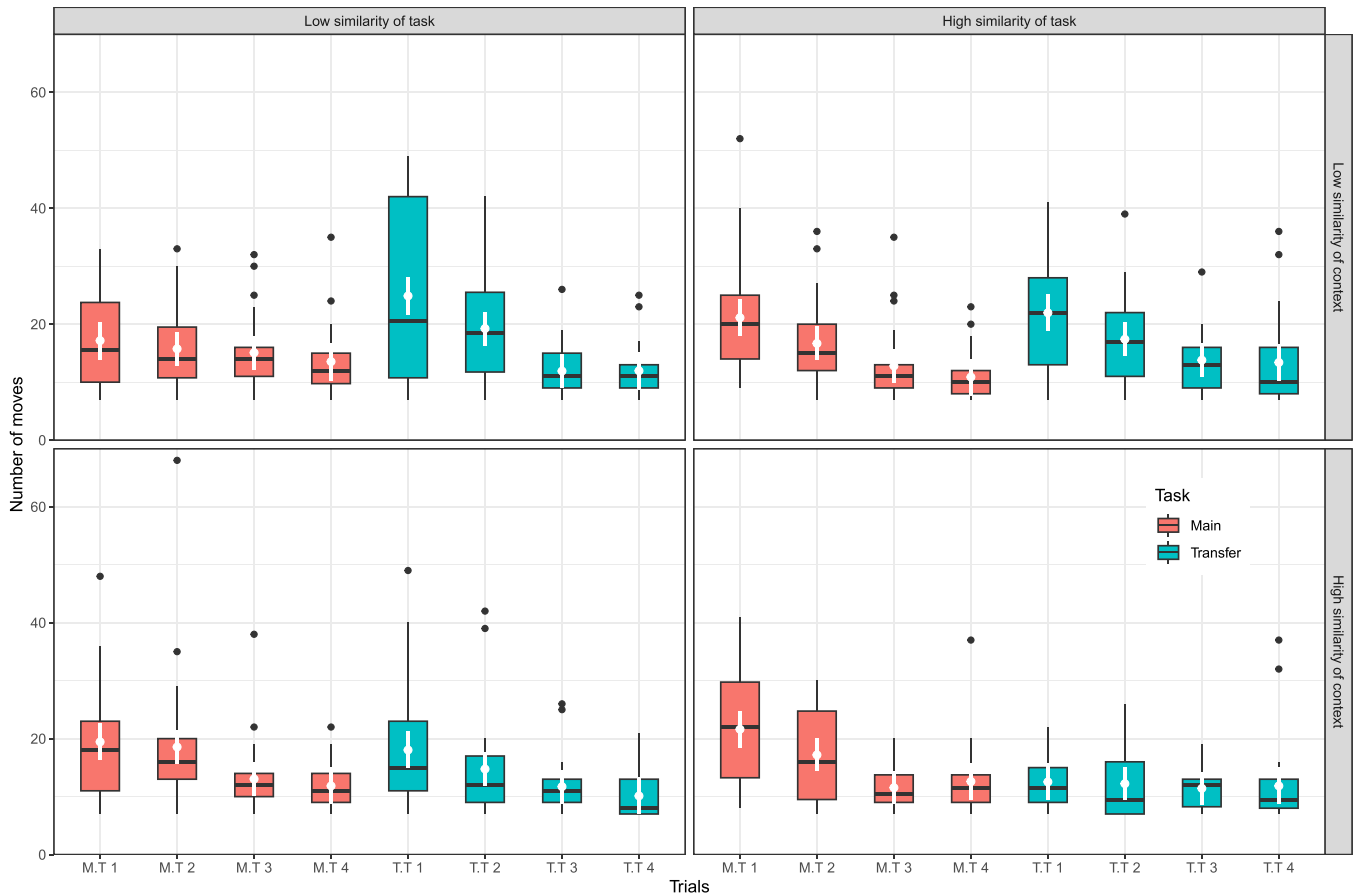


Fig. 2. Mean number of moves on each trial as a function of degree of similarity and task. M.T. = Main Task; T.T. = Transfer Task.

children performed the first trial in the same number of moves as the second trial ( $M = 19.3, SD = 9.54, p = 1$ ), but they used significantly fewer moves to perform the third trial ( $M = 11.9, SD = 4.48$ ) than both the first and the second trials,  $ps < .001$ . They also took fewer moves to perform the fourth trial ( $M = 12, SD = 4.53$ ) than both the first and the second trials,  $ps < .001$ . There was no significant difference between trial 3 and trial 4 in the transfer task. Furthermore, in the first transfer trial, the number of moves was lower in the H/H condition than in L/H condition. Similarly, the decrement in performance observed in the L/L and H/L conditions was less pronounced in the H/L condition than in the L/L condition (Fig. 2). No other significant effect was found.

### 3.2. Inhibition analysis of number of moves

To standardize the inhibition scores, Z-scores were computed, and results from children with  $\pm 2$  standard deviations from the mean (outliers) were removed from the sample, which resulted in excluding data from five children. The analyses on inhibition scores were thus performed on  $N = 95$ . To test the predictive effect of inhibitory control on transfer performance in the ToH test, we conducted a multiple regression analysis, with the number of moves on all eight trials (four trials of the main task and four trials of the transfer task) as the dependent variables, and the scores on the Day and Night, and HTKS tests as predictors. We chose to consider all trials to ensure that inhibition scores only predicted transfer performance (transfer task) and not learning performance (main task).

Regarding the main task, inhibition scores predicted performance only in the first trial [ $F(2, 92) = 11.15, p < .001, \text{adjusted } R^2 = 0.18, \beta = 0.44, b_0 = 38.89$ ], but this was not the case for the other three trials. In contrast, inhibition scores predicted performance in the first [ $F(2, 92) =$

Table 2

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

Trial	Predictor	$\beta$	$b_1$	$p$
Trial 1	Day and Night	-.40	-1.08	.001
	HTKS	-.10	-.08	.32
Trial 2	Day and Night	-.36	-.71	.001
	HTKS	-.04	-.03	.66
Trial 3	Day and Night	-.13	-.14	.20
	HTKS	-.26	.09	.01
Trial 4	Day and Night	.18	.25	.08
	HTKS	-.28	-.12	.01

$10.5, p < .001, \text{adjusted } R^2 = 0.17, \beta = 0.43, b_0 = 44.88$ ], second [ $F(2, 92) = 7.38, p < .001, \text{adjusted } R^2 = 0.12, \beta = 0.37, b_0 = 31.33$ ], third [ $F(2, 92) = 5.30, p = .01, \text{adjusted } R^2 = 0.08, \beta = 0.32, b_0 = 18.69$ ], and fourth [ $F(2, 92) = 4.49, p = .01, \text{adjusted } R^2 = 0.07, \beta = 0.29, b_0 = 11.77$ ] trials of the transfer task. Results for the transfer trials are displayed in Table 2.

Overall, these results indicate that the performance on the first and second transfer trials was predicted by cognitive inhibition (Day and Night) whereas the performance on the third and fourth trials was predicted by behavioral inhibition (HTKS).

## 4. Discussion

The first aim of this study was to determine the contribution of similarity between tasks and similarity between their contexts of presentation, to transfer decrement in children. This amounts to supporting the model of Klahr and Chen (2011) in an original way, by manipulating

context similarity and dis-similarity on a digital tablet by changing the seductive details.

The second aim was to study the temporal dynamics of performance in transfer of learning in children. This question is usually incidental to the study of transfer of learning. However, it provides valuable information about the trajectory of learning and transfer in children.

The third aim was to study the implication of inhibitory control in the transfer of learning in problem solving with digital devices.

#### 4.1. Model of Klahr and Chen (2011)

The model of Klahr and Chen (2011) predicts that transfer is less successful when both the tasks and their contexts are dis-similar. According to this prediction, our results showed that in the Low similarity of tasks/Low similarity of contexts (L/L) condition, children's performance decreased from the last trial of the main task to the first trial of the transfer task, attesting to a decrement in transfer performance. Surprisingly, this was also the case in the High similarity of tasks/Low similarity of contexts (H/L) condition, despite the high degree of tasks' similarity. In contrast, children tested using the Low similarity of tasks/High similarity of contexts (L/H) condition and the High similarity of tasks/High similarity of contexts (H/H) condition solved the first trial of the transfer task in the same number of moves as the last trial of the main task, attesting to an absence of any decrement in transfer performance. These results shed some light on the role of similarity between the digital contexts, especially the seductive details included in the graphical interface. Some studies have shown that seductive details hinder task learning (Wang & Adesope, 2014). Seductive details distract the learner, engaging him in irrelevant processing and diverting him from the task. In the L/L and H/L conditions, in which a decrement at transfer was observed, the digital context of the transfer task (coconut trees) was semantically different from the digital context of the main task (house); while in the L/H and H/H conditions, in which no decrement at transfer was observed, the contexts of the two tasks were semantically more similar (shrubs and coconut trees respectively). Thus, context seems to play an important role in transfer. This is consistent with previous research showing that problem-solving rules are so embedded within their contexts of presentation that their transfer is highly dependent on contextual similarity (Clément and Richard, 1997; Klahr & Chen, 2011; Kotovsky & Fallside, 1989). It is likely that the main task was mentally encoded in a representation including the seductive details, which act as a digital context of presentation. A change in the seductive details in the transfer task would then have hindered the transfer of the procedure for solving the ToH that was built in the main task. This in turn may easily explain the decrement in transfer performance observed in L/L and H/L conditions, making the transfer task resemble a new one. In contrast, in the L/H and H/H conditions, it is likely that the digital context of the transfer task, which was more similar to the context of the main task, served as a recall cue for the ToH procedure. This in turn allowed children to detect the similarity between the two contexts and the associated tasks, and then transfer the procedure from the main task to the transfer task. Thus, the similarity of contexts seems to have played a greater role than the similarity of tasks. Taken together, the results of this study provide original support of the model of Klahr and Chen (2011) and extend it by using digital tasks and digital contexts. Indeed, low degrees of similarities of tasks and contexts led to a decrement at transfer whereas no such decrement was observed with high degrees of these two kinds of similarity. Surprisingly, the weight of the similarity of digital contexts was found to be stronger than those of digital tasks *per se*, which adds to our conceptual understanding of transfer. Decrement in transfer performance seems to be influenced both by the degree of similarity between tasks and between contexts (e.g., high; intermediate; low) and by the kind of similarity (tasks vs. contexts). This confirms that near and far transfers are so defined on a continuum in which performance progressively decreases as differences widen, either between tasks, between contexts, or both. Thus, considering the difference

between near transfer and far transfer as dichotomic would be erroneous, since a slight variation in context can lead to a decrement in transfer performance even though the tasks are very similar, as is the case in the present study.

#### 4.2. Temporal dynamics

Learning does not always follow a linear pattern. On the contrary, sometimes it alternates between failure and success (Chen & Klahr, 1999; Mombo & Clerc, 2022). The results of this study showed a rebound in transfer performance in the L/L condition, attested by a significantly lower number of moves on the third trial of the transfer task compared to the first and second trials of the same task. This rebound in performance was maintained from the third to the fourth trial. The difference with other conditions lies in the presence, in the L/L condition, of two sources of dis-similarities namely the context and the task itself. Thus, this rebound may be due to a gradual adaptation as children complete the task. Because the seductive details surrounding the transfer task were novel, children likely processed the transfer task as a new task, without considering the main task. Furthermore, a low degree of similarity of contexts between the main task and the transfer task makes the semantic distance between the two tasks higher. Both the semantic distance and the perceptual differences between the main task and the transfer task, in turn, were likely to make a child hesitate concerning what to do in this new task presented in a new context. Thus, the first and second transfer trials probably served as an exploratory phase (Clément & Richard, 1997; Kotovsky, Hayes, & Simon, 1985), leading children to focus one's attention on seductive details and thus hindering them from processing the task itself. In the last two transfer trials, a higher familiarity of the digital context likely allowed the children to ignore the seductive details, leading to perform better.

An alternative explanation of the rebound in performance lies in uncertainty. Uncertainty leads children to engage in the task, persist, and thereby process the task in depth (Lamnina & Chase, 2021). In the present study, children may have engaged in the first transfer trial; failed to process it at the same level of performance as the fourth trial of the main task, leading to a larger number of moves in the first transfer trial; persisted in the transfer task, despite its difficulty coming from its new digital context; and finally processed the transfer task in depth, leading to the same number of moves from the third transfer trial onward by overcoming the dissimilarities between the digital contexts of the main task and of the transfer task. The role of uncertainty in learning and transfer is still controversial (Lamnina & Chase, 2021), but given the prominent role of uncertainty in children's cognitive development (Ghetti, Hembacher, & Coughlin, 2013), whether the observed decrease-then-rebound temporal pattern traduces the role of uncertainty in transfer in young children deserves more research.

Using a digital tablet, this study allowed digital contexts to be varied and different cases of decrease-then-rebound patterns to appear, permitting us to advance our understanding of transfer. Indeed, in contrast to the L/L condition already discussed, in the H/L condition there was no rebound of performance. Whereas in both conditions the contexts differed from the main to the transfer task, in the H/L condition the transfer task itself was perceptually similar to the main task, since both tasks used similar stackable pieces. This perceptual similarity between tasks may explain the lack of performance rebound, when compared to the recovery of the L/L condition. Indeed, due to its two sources of dis-similarities, the L/L condition seems to have increased the need for exploration of the transfer task. It is likely that children in the L/L condition explored the transfer task on the first trial, and processed it more deeply on the second trial, leading in turn to a rebound of performance in the last two transfer trials. In contrast, with a single source of dis-similarity that decreased their performance at transfer, children in the H/L condition were unlikely to perform deep processing to significantly recover their performance after the performance decrement. Nevertheless, although there is a performance recovery in the L/L



condition, this performance is still slightly lower than in the H/L condition, in which there was no significant recovery of performance. This supports again the model of [Klahr and Chen \(2011\)](#), by showing that more dis-similarities (between tasks and contexts) make transfer more difficult by making decrement in transfer more pronounced compared to a condition with a single dis-similarity source.

The use of perceptually different stackable pieces was made possible in this study by the digital tablet. It allowed a very precise, fine-grained, physical definition of the perceptual properties of the two versions of the ToH task that would have been difficult to reach with a tangible, rather than a numerical, apparatus. Furthermore, even though the perceptual differences between the two tasks may be considered negligible (rectangles vs disks), they gave rise to a proper phenomenon of decrement in transfer. This advances our theoretical understanding of this phenomenon, by showing that even very slight differences between two tasks can make a decrement in transfer appear. In light of this, decrement in transfer should have been massively observed in transfer literature. Yet, this is not the case. Indeed, a great deal of transfer studies did not even report any decrement in transfer whereas studies in several domains showed such a decrement ([Adi-Japha & Brestel, 2020](#); [Clerc & Miller, 2013](#); [Clerc et al., 2021](#); [Gellert, Arnbak, Wischmann, & Elbro, 2021](#); [Moser et al., 2015](#); [Resing, Bakker, Pronk, & Elliott, 2016](#); [Schiff & Vakil, 2015](#)). We argue that this decrement may have been neglected in past studies, maybe due to a positivity bias leading researchers in developmental and educational psychology to seek for successful transfer rather than transfer difficulties or obstacles. Obviously, almost a half-century of research in children aimed to identify the conditions of successful cognitive transfer ([Borkowski, Levers, & Gruenfelder, 1976](#); [Brown & Kane, 1988](#); [Cartwright et al., 2020](#); [van Bers, van Schijndel, Visser, & Raijmakers, 2020](#)). Our results also confirm and extend the role of adaptation in transfer ([Nokes, 2009](#); [Opfer & Thompson, 2008](#); [Schwartz et al., 2012](#)), since even a very small change between a main task and a transfer task requires adaptation. Adaptation is likely to have a cognitive cost, whose decrement in transfer is likely to be a consequence ([Clerc et al., 2014](#)). In brief, in this study a digital apparatus revealed some subtleties of the cognitive processes involved in transfer of learning, thanks to the high degree of precision that it permits both in the tasks presented on a tablet and in the digital contexts in which those tasks are embedded.

#### 4.3. Implication of inhibitory control in transfer with digital devices

The results of this study showed that inhibition scores predicted performance on the first trial of the main task, but not on the last three trials of this task. In contrast, inhibition scores predicted performance on all trials of the transfer task. [Richard, Poitrenaud, and Tijus \(1993\)](#) argued that when solving a problem, the learner creates spontaneously some of his/her own implicit constraints that conflict with the constraints imposed by the task (e.g., the task's resolution rules). To solve a problem, it is necessary for the learner to arbitrate this conflict, by removing or inhibiting his implicit constraints. In this study, it may be that during the first trial of the main task, in the midst of building a cognitive procedure for solving the problem, children mobilized inhibitory control. It may have allowed them to effectively maintain their implicit constraints, acting as intrusive information, at distance from working memory ([Diamond, 2013](#)). After the problem-solving procedure has been built during the first trial, children may no longer need inhibitory control to complete the remaining three trials of the main task. Regarding the predictive effect of inhibition scores on performance in the four transfer trials, one possible explanation is that when performing the transfer task, children continuously inhibited interference arising from differences between digital tasks and between digital contexts of presentation. Indeed, to process the transfer task by transferring the procedure that was built into the main task, it is necessary to ignore the seductive details presented on the interface of the transfer task constantly and deliberately.

Another result of great interest is that cognitive inhibition, i.e., inhibition of interference arising from differences between tasks and between digital contexts of presentation, was involved in the first two transfer trials, while behavioral response inhibition, that is control of moves to be performed, was involved in the last two transfer trials. Thus, inhibitory control was involved in the transfer of the cognitive procedure between two isomorphic digital ToH tasks. However, the two facets of inhibitory control (cognitive inhibition and behavioral inhibition, [Diamond, 2013](#)) were involved at different times. To the best of our knowledge, no study has reported this result previously. This result may be explained by the nature of the ToH tasks. Indeed, ToH involves planning for legal moves, which requires both ignoring illegal moves and removing the motor response of those illegal moves. It may also be explained by the digital format of presentation of the tasks and their contexts. Indeed, when the seductive details surrounding the transfer task are different from those surrounding the main task, this leads to interferences due to the semantic dis-similarity between these seductive details. Such interferences must be controlled to transfer efficiently. Moreover, moving a stackable piece from one location to another by sliding the finger is easy, but when moving the stackable piece to a specific location is needed it requires motor control not to let the finger slide and put the stackable piece in a prohibited location. The fact that two different aspects of inhibitory control are involved subsequently in four identical trials of the same task advances our theoretical understanding of both transfer and inhibition.

#### 4.4. Limitations

Results of this study supported the model of [Klahr and Chen \(2011\)](#), by manipulating digital contexts' similarity and dis-similarity on a graphical interface by changing the seductive details. Nevertheless, it has some limitations that may lead to further studies. This study has shown that the weight of similarity of digital contexts is stronger than that of digital tasks *per se*. However, this result was found with digital devices only. Future studies should try to replicate this with tangible materials. Furthermore, in this study we varied the learning context by changing the seductive details surrounding the task. Nevertheless, we did not use a blank screen condition (e.g., a control condition), which would have allowed us to test the role of seductive details more finely.

Regarding inhibition, the model of [Diamond \(2013\)](#) includes three dimensions of inhibitory control which are behavioral response inhibition, cognitive inhibition and attentional-level inhibition. In this study we only measured the first two dimensions. The third dimension, attentional-level inhibition, allows the interference between elements of indeterminate nature to be controlled for. Replicating this study while measuring also the third dimension might be of interest. Indeed, if two different digital contexts of presentation are defined by different seductive details, the seductive details surrounding the transfer task constitute interfering stimuli that the child must inhibit. It appears that the required inhibition may correspond to what [Diamond \(2013\)](#) refers to as attentional-level inhibition, usually measured by Flanker-type tasks. Future studies may add such a measure to assess the potential contribution of attentional-level inhibition to the transfer between two digital ToH tasks in children.

#### 5. Conclusion

This study shows that both similarity of tasks and similarity of contexts determine transfer, bringing new knowledge to the theoretical framework of similarity of tasks and similarity of contexts in transfer of learning ([Klahr & Chen, 2011](#)). This was made possible by presenting several versions of the ToH task on digital devices. The use of a digital context revealed some subtleties of the cognitive processes involved in the transfer of learning in children. The results of this study shed light on a decrease-then-rebound pattern that had seemingly been understudied in the transfer of learning in children. They also offer new perspectives

for a deeper understanding of the role of inhibition in transfer, and of the processes that may explain the pattern of decrease-then-rebound performance observed in this study.

Successful transfer in children is an important issue, especially at school since it promotes adaptability and in turn academic achievement. From this point of view, conditions for successful transfer should give rise to more research with practical applications in mind. Successful transfer may be one of the most important topics in applied educational psychology research in the near future. Yet, in a more theoretical attempt, cases of decrement in transfer still deserve to be explained. As already mentioned, several studies in the past showed that decrement in transfer is not as rare a phenomenon, giving credit to any research efforts in this direction.

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## CRediT authorship contribution statement

**Wilfried T. Mombo:** Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Laureen Jossieron:** Methodology, Visualization, Writing – review & editing. **Jean-Charles Quinton:** Formal analysis, Methodology, Writing – review & editing. **Jerome Clerc:** Conceptualization, Methodology, Supervision, Writing – original draft, Writing – review & editing.

## Declaration of competing interest

We, the undersigned Wilfried Mombo, Laureen Jossieron, Jean-Charles Quinton and Jérôme Clerc, certify that data reported in this paper have not been submitted to another journal. All coauthors have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

## Data availability

Data will be made available on request.

## References

- Adi-Japha, E., & Brestel, G. (2020). Motor skill learning with impaired transfer by children with developmental coordination disorder. *Research in Developmental Disabilities, 103*, Article 103671. <https://doi.org/10.1016/j.ridd.2020.103671>
- Aladé, F., Lauricella, A. R., Beaudoin-Ryan, L., & Wartella, E. (2016). Measuring with murray: Touchscreen technology and preschoolers' STEM learning. *Computers in Human Behavior, 62*, 433–441. <https://doi.org/10.1016/j.chb.2016.03.080>
- Barnett, S. M., & Ceci, S. J. (2002). When and where do we apply what we learn? A taxonomy for far transfer. *Psychological Bulletin, 128*(4), 612–637. <https://doi.org/10.1037/0033-2909.128.4.612>
- Beaunieux, H., Hubert, V., Witkowski, T., Pitel, A. L., Rossi, S., Danion, J. M., et al. (2006). Which processes are involved in cognitive procedural learning? *Memory, 14*(5), 521–539. <https://doi.org/10.1080/09658210500477766>
- van Bers, B. M. C. W., van Schijndel, T. J. P., Visser, I., & Raijmakers, M. E. J. (2020). Cognitive flexibility training has direct and near transfer effects, but no far transfer effects, in preschoolers. *Journal of Experimental Child Psychology, 193*, Article 104809. <https://doi.org/10.1016/j.jecp.2020.104809>
- Borkowski, J. G., Levers, S., & Gruenenfelder, T. M. (1976). Transfer of mediational strategies in children: The role of activity and awareness during strategy acquisition. *Child Development, 47*(3), 779. <https://doi.org/10.2307/1128194>
- Brown, A. L., & Kane, M. J. (1988). Preschool children can learn to transfer: Learning to learn and learning from example. *Cognitive Psychology, 20*, 493–523.
- Cartwright, K. B., Bock, A. M., Clause, J. H., Coppage August, E. A., Saunders, H. G., & Schmidt, K. J. (2020). Near- and far-transfer effects of an executive function intervention for 2nd to 5th-grade struggling readers. *Cognitive Development, 56*, Article 100932. <https://doi.org/10.1016/j.cogdev.2020.100932>
- Chen, Z., & Klahr, D. (1999). All other things being equal: Acquisition and transfer of the control of variables strategy. *Child Development, 70*(5), 1098–1120. <https://doi.org/10.1111/1467-8624.00081>
- Clément, E., & Richard, J.-F. (1997). Knowledge of domain effects in problem representation: The case of Tower of Hanoi isomorphs. *Thinking & Reasoning, 3*(2), 133–157. <https://doi.org/10.1080/135467897394392>
- Clerc, J., Leclercq, M., Paik, J., & Miller, P. H. (2021). Cognitive flexibility and strategy training allow young children to overcome transfer-Utilization Deficiencies. *Cognitive Development, 57*, 2–15. <https://doi.org/10.1016/j.cogdev.2020.100997>
- Clerc, J., & Miller, P. H. (2013). Utilization deficiencies and transfer of strategies in preschoolers. *Cognitive Development, 28*(1), 76–93. <https://doi.org/10.1016/j.cogdev.2012.09.003>
- Clerc, J., Miller, P. H., & Cosnefroy, L. (2014). Young children's transfer of strategies: Utilization deficiencies, executive function, and metacognition. *Developmental Review, 34*(4), 378–393. <https://doi.org/10.1016/j.dr.2014.10.002>
- Corbalan, G., Kester, L., & Van Merriënboer, J. J. (2011). Learner-controlled selection of tasks with different surface and structural features: Effects on transfer and efficiency. *Computers in Human Behavior, 27*(1), 76–81. <https://doi.org/10.1016/j.chb.2010.05.026>
- Cox, B. D. (1997). The rediscovery of the active learner in adaptive contexts: A developmental-historical analysis of transfer of training. *Educational Psychologist, 32*(1), 41–55. [https://doi.org/10.1207/s15326985ep3201\\_4](https://doi.org/10.1207/s15326985ep3201_4)
- Day, S. B., & Goldstone, R. L. (2012). The import of knowledge export: Connecting findings and theories of transfer of learning. *Educational Psychologist, 47*(3), 153–176. <https://doi.org/10.1080/00461520.2012.696438>
- Diamond, A. (2013). Executive functions. *Annual Review of Psychology, 64*(1), 135–168. <https://doi.org/10.1146/annurev-psych-113011-143750>
- Diamond, A. (2020). Executive functions. In A. Gallagher, C. Bulteau, D. Cohen, & J. L. Michaud (Eds.), *Handbook of clinical neurology/Neurocognitive development: Normative development* (pp. 225–240). Amsterdam: Elsevier. <https://doi.org/10.1016/B978-0-444-64150-2.00020-4>
- Faul, F., Erdfelder, E., Buchner, A., & Lang, A. G. (2009). Statistical power analyses using G\* Power 3.1: Tests for correlation and regression analyses. *Behavior Research Methods, 41*(4), 1149–1160. <https://doi.org/10.3758/BRM.41.4.1149>
- Gellert, A. S., Arnbak, E., Wischmann, S., & Elbro, C. (2021). Morphological intervention for students with limited vocabulary knowledge: Short- and long-term transfer effects. *Reading Research Quarterly, 56*(3), 583–601. <https://doi.org/10.1002/rq.325>
- Gerstadt, C. L., Hong, Y. J., & Diamond, A. (1994). The relationship between cognition and action: Performance of children 3 1/2-7 years old on a Stroop-like day-night test. *Cognition, 53*(2), 129–153. [https://doi.org/10.1016/0010-0277\(94\)90068-X](https://doi.org/10.1016/0010-0277(94)90068-X)
- Ghetti, S., Hembacher, E., & Coughlin, C. A. (2013). Feeling uncertain and acting on it during the preschool years: A metacognitive approach. *Child Development Perspectives, 7*(3), 160–165. <https://doi.org/10.1111/cdep.12035>
- Gick, M. L., & Holyoak, K. J. (1987). The cognitive basis of knowledge transfer. In S. Cormier, & J. Hagman (Eds.), *Transfer of learning: Contemporary research and applications* (pp. 9–46). San Diego: Academic Press. <https://doi.org/10.1016/C2009-0-21745-4>
- Helsdingen, A., van Gog, T., & van Merriënboer, J. (2011). The effects of practice schedule and critical thinking prompts on learning and transfer of a complex judgment task. *Journal of Educational Psychology, 103*(2), 383–398. <https://doi.org/10.1037/a0022370>
- Hirsh-Pasek, K., Zosh, J. M., Golinkoff, R. M., Gray, J. H., Robb, M. B., & Kaufman, J. (2015). Putting education in “educational” apps: Lessons from the science of learning. *Psychological Science in the Public Interest, 16*(1), 3–34. <https://doi.org/10.1177/1529100615569721>
- Huber, B., Tarasuik, J., Antoniou, M. N., Garrett, C., Bowe, S. J., & Kaufman, J. (2016). Young children's transfer of learning from a touchscreen device. *Computers in Human Behavior, 56*, 56–64. <https://doi.org/10.1016/j.chb.2015.11.010>
- Klahr, D., & Chen, Z. (2011). Finding one's place in transfer space. *Child Development Perspectives, 5*(3), 196–204. <https://doi.org/10.1111/j.1750-8606.2011.00171.x>
- Kotovsky, K., & Fallside, D. (1989). Representation and transfer in problem solving. In K. Kotovsky (Ed.), *Complex information processing. What has Simon brought? 21<sup>st</sup> symposium of the Carnegie Mellon Institute*. Hillsdale, NJ: Lawrence Erlbaum Associates, Inc.
- Kotovsky, K., Hayes, J. R., & Simon, H. A. (1985). Why are some problems hard? Evidence from tower of Hanoi. *Cognitive Psychology, 17*(2), 248–294. [https://doi.org/10.1016/0010-0285\(85\)90009-X](https://doi.org/10.1016/0010-0285(85)90009-X)
- Lamnina, M., & Chase, C. C. (2021). Uncertain instruction: Effects on curiosity, learning, and transfer. *Instructional Science, 49*(5), 661–685. <https://doi.org/10.1007/s11251-021-09557-2>
- Major, L., Häbler, B., & Hennessy, S. (2017). Tablet use in schools: Impact, affordances and considerations. In A. Marcus-Quinn, & T. Hourigan (Eds.), *Handbook on digital learning for K-12 Schools* (pp. 115–128). Springer International Publishing. [https://doi.org/10.1007/978-3-319-33808-8\\_8](https://doi.org/10.1007/978-3-319-33808-8_8)
- Mayer, R. E. (2008). Applying the science of learning: Evidence-based principles for the design of multimedia instruction. *American Psychologist, 63*(8), 760–769. <https://doi.org/10.1037/0003-066X.63.8.760>
- Mombo, W. T., & Clerc, J. (2022). Transfer of learning in young children: Magic digital or similarity-based? *L'Année Psychologique/Topics in Cognitive Psychology, 122*(3), 471–512. <https://doi.org/10.3917/anpsy1.223.0471>
- Moreno, R. (2005). Instructional technology: Promise and pitfalls. In L. PytkilZillig, M. Bodvarsson, & R. Bruning (Eds.), *Technology-based education: Bringing researchers and practitioners together (1-19)*. Greenwich, CT: Information Age Publishing.

- Moreno, R. (2006). Does the modality principle hold for different media? A test of the method-affects-learning hypothesis. *Journal of Computer Assisted Learning*, 22(3), 149–158. <https://doi.org/10.1111/j.1365-2729.2006.00170>
- Moser, A., Zimmermann, L., Dickerson, K., Grenell, A., Barr, R., & Gerhardstein, P. (2015). They can interact, but can they learn? Toddlers' transfer learning from touchscreens and television. *Journal of Experimental Child Psychology*, 137, 137–155. <https://doi.org/10.1016/j.jecp.2015.04.002>
- Nokes, T. (2009). Mechanisms of knowledge transfer. *Thinking & Reasoning*, 15(1), 1–36.
- Opfer, J. E., & Thompson, C. A. (2008). Costs and benefits of representational change: Effects of context on age and sex differences in symbolic magnitude estimation. *Journal of Experimental Child Psychology*, 101(1), 20–51. <https://doi.org/10.1016/j.jecp.2008.02.003>
- Perruchet, P., & Vinter, A. (2002). The self-organizing consciousness. *Behavioral and Brain Sciences*, 25(3), 297–330. <https://doi.org/10.1017/S0140525X02000067>
- Ponitz, C. C., McClelland, M. M., Matthews, J. S., & Morrison, F. J. (2009). A structured observation of behavioral self-regulation and its contribution to kindergarten outcomes. *Developmental Psychology*, 45(3), 605–619. <https://doi.org/10.1037/a0015365>
- Resing, W. C. M., Bakker, M., Pronk, C. M. E., & Elliott, J. G. (2016). Dynamic testing and transfer: An examination of children's problem-solving strategies. *Learning and Individual Differences*, 49, 110–119. <https://doi.org/10.1016/j.lindif.2016.05.011>
- Richard, J.-F. (1982). Planification et organisation des actions dans la résolution du problème de la Tour de Hanoi par des enfants de 7 ans [Planning and organization of actions in solving the Tower of Hanoi problem by 7-year-olds]. *L'Année Psychologique/Topics in Cognitive Psychology*, 82(2), 307–336. <https://doi.org/10.3406/psy.1982.28422>
- Richard, J.-F., Poitrenaud, S., & Tijus, C. (1993). Problem-solving restructuring: Elimination of implicit constraints. *Cognitive Science*, 17(4), 497–529. [https://doi.org/10.1207/s15516709cog1704\\_2](https://doi.org/10.1207/s15516709cog1704_2)
- Schiff, R., & Vakil, E. (2015). Age differences in cognitive skill learning, retention and transfer: The case of the Tower of Hanoi puzzle. *Learning and Individual Differences*, 39, 164–171. <https://doi.org/10.1016/j.lindif.2015.03.010>
- Schwartz, D. L., Chase, C. C., & Bransford, J. D. (2012). Resisting overzealous transfer: Coordinating previously successful routines with needs for new learning. *Educational Psychologist*, 47(3), 204–214. <https://doi.org/10.1080/00461520.2012.696317>
- Siegler, R. S. (2006). Microgenetic analyses of learning. In W. Damon, R. M. Lerner, D. Kuhn, & R. S. Siegler (Eds.) (6th ed., *Cognition, perception, and language: Vol. 2. Handbook of child psychology* (pp. 464–510). New York: Wiley.
- Simpson, A., & Riggs, K. J. (2005). Inhibitory and working memory demands of the day-night task in children. *British Journal of Developmental Psychology*, 23(3), 471–486. <https://doi.org/10.1348/026151005X28712>
- Simpson, A., Riggs, K. J., Beck, S. R., Gorniak, S. L., Wu, Y., Abbott, D., et al. (2012). Refining the understanding of inhibitory processes: How response prepotency is created and overcome. *Developmental Science*, 15(1), 62–73. <https://doi.org/10.1111/j.14677687.2011.01105.x>
- Tarasuik, J., Demaria, A., & Kaufman, J. (2017). Transfer of problem-solving skills from touchscreen to 3D model by 3- to 6-year-olds. *Frontiers in Psychology*, 8, 1–6. <https://doi.org/10.3389/fpsyg.2017.01586>
- Thibaut, J.-P., French, R., & Vezneva, M. (2010). The development of analogy making in children: Cognitive load and executive functions. *Journal of Experimental Child Psychology*, 106(1), 1–19. <https://doi.org/10.1016/j.jecp.2010.01.001>
- Thibaut, J.-P., French, R. M., Vezneva, M., Gérard, Y., & Glady, Y. (2011). Semantic analogies by young children: Testing the role of inhibition. In B. Kokinov, A. Karmiloff-Smith, & N. J. Nersessian (Eds.), *European perspectives on cognitive science* (pp. 136–141). Sofia: New Bulgarian University Press.
- Wang, Z., & Adesope, O. (2014). Effects of seductive details on multimedia learning. *Journal of Studies in Education*, 4(3), 32. <https://doi.org/10.5296/jse.v4i3.6024>
- Zack, E., Barr, R., Gerhardstein, P., Dickerson, K., & Meltzoff, A. N. (2009). Infant imitation from television using novel touch screen technology. *British Journal of Developmental Psychology*, 27(1), 13–26. <https://doi.org/10.1348/026151008X334700>