



HAL
open science

Digital touchscreens as a media for creativity during adolescence

Fabien Bitu, Béatrice Galinon-Mélénez, Michèle Molina

► **To cite this version:**

Fabien Bitu, Béatrice Galinon-Mélénez, Michèle Molina. Digital touchscreens as a media for creativity during adolescence. *L'Année psychologique*, 2021, 121 (4), pp.489 - 518. 10.3917/anpsy1.214.0489 . hal-03673465

HAL Id: hal-03673465

<https://hal.science/hal-03673465>

Submitted on 20 May 2022

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers.

L'archive ouverte pluridisciplinaire **HAL**, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d'enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.

Title:
Digital touchscreens as a media for creativity during adolescence

Authors & institutions :
Fabien Bitu^a, Béatrice Galinon-Méléne^b, and Michèle Molina^a

^aLaboratory of Psychology of Caen Normandy, LPCN EA7452 – University of Caen Normandy

^bIdentity and Differentiation of Spaces, Environment and Societies, UMR IDEES 6266 CNRS - University Le Havre Normandy

Running title:
Creativity in digital drawings

Corresponding author:
Fabien Bitu
UFR de Psychologie,
Bâtiment L, 4e étage - porte SE 403
Esplanade de la Paix
14032 CAEN Cedex
FRANCE

Mail: fabien.bitu@unicaen.fr

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

Declarations of interest: none.

Author's note

Fabien Bitu, ORCID iD: <https://orcid.org/0000-0002-4507-042X>

This article has been accepted for publication in *L'Année psychologique/Topics in cognitive Psychology* on July 23, 2021. It is available online in the editor's format at the following link: <https://doi.org/10.3917/anpsy1.214.0489>

To cite this article: Bitu, F., Galinon-Méléne, B., & Molina, M. (2021). Digital touchscreens as a media for creativity during adolescence. *L'Année psychologique*, 121(4), 489-518.

Abstract

Based on embodied representation theory (Pezzulo, 2011) considering creativity process as a predictive motor control process (Dietrich & Haider, 2015), this research was aimed at evaluating whether direct finger feedbacks on tablet could promote originality in drawings. Twenty-one adolescents aged 13/14 were asked to produce the most original house as possible on tablet with finger and stylus and on paper with a pen, and an unoriginal house with a pen on paper. Originality in drawing was scored with a rating scale comparing original drawings to a prototypical house, then comparing original drawings to unoriginal ones. Results revealed that original scores are higher for drawings on tablet (without difference between finger and stylus) than on paper. These findings highlight the role played by off-line simulation of action in the creative process.

Résumé

Basée sur les théories de la représentation incarnée (Pezzulo, 2011) considérant le processus créatif comme un contrôle moteur prédictif (Dietrich & Haider, 2015), cette recherche a évalué le potentiel de la tablette tactile comme un outil facilitant l'originalité des dessins. Vingt-et-un adolescents âgés de 13/14 ans ont été invités à produire la maison la plus originale possible sur tablette au doigt et au stylet ainsi que sur papier, et une maison non-originale avec un crayon sur papier. L'originalité des dessins a été notée avec une échelle de cotation comparant les dessins originaux à une maison prototypique, puis en comparant les dessins originaux aux dessins non originaux. Les résultats montrent que les scores d'originalité sont supérieurs pour les dessins réalisés sur tablette (sans différence entre doigt et stylet) plutôt que sur papier. Ces résultats mettent en évidence le rôle joué par le processus de simulation off-line de l'action dans le processus créatif.

1. Introduction

Nowadays, digital technologies are commonly used in occidental societies, especially mobile devices like smartphones and tablets which are respectively used by 84% and 73% of 13 to 18 years old in US, for a total of 3:27 average time spent per day on these two devices (Rideout, 2016). Touchscreens, defined as electronic devices presenting a visual screen controlled by gestures and tactile actions executed with fingers or stylus (Dubé & McEwen, 2015), such as smartphones or tablets, are among the most popular devices used by children and adolescents. These media offer a multimodal interaction, stimulating visual, tactile-kinesthetic and proprioceptive sensorial systems, which help in maintaining attention (Roskos, Burstein, Shang, & Gray, 2014). Touchscreen devices are particularly easy to use since few formal knowledge and only simple gestures are required to interact directly with hand and fingers (Dubé & McEwen, 2015; McManis & Gunnewig, 2012). The possibility to act directly with fingers would contribute most particularly to the easiness of use of this device, even at a young age (Cooper, 2005; Geist, 2012; McManis & Gunnewig, 2012; Piotrowski & Meester, 2018; Sakr, 2018), by providing an immediate feedback to fingertips on screen at each gestural actions, as well as releasing the user from the sensorimotor constraints consecutive to the motor control of the pen. Beyond the benefice that the finger actions can offer in the easiness of use of touchscreen devices, the question remains to know whether these direct feedbacks may have an impact on the mobilization of cognitive processes. More specifically, in this paper, we will ask whether drawing with fingers on tablet can facilitate drawing creativity. Various definitions of creativity have been proposed through the years (Duff, 1767; James, 1880; Spearman, 1931), bringing closer the concept of originality in creativity since William James (1880). We chose to retain the most consensual definition of creativity as the ability to realize something new and adapted to the context of action (Lubart, Mouchiroud, Tordjam, & Zenasni, 2003). In this

definition, creativity is based on three components that are, according to Mouchiroud and Lubart (2001), fluency (number of relevant responses), flexibility (number of themes in responses), and originality (unusualness of responses). Originality is thus the component of creativity which specifically describes the novelty of a creative idea (Lubart & Georgsdottir, 2004; Mouchiroud & Lubart, 2001). Originality in drawing would then correspond to the specific aspects of the drawing that have been assessed and selected as novel, depending on the acquired knowledge about the drawn subject (Lubart & Georgsdottir, 2004; Runco, 1991).

Recently, creative thinking has been conceived as arising from sensorimotor control processes (Dietrich & Haider, 2014), and more specifically from sensorimotor prediction (Pezzulo, 2011). Sensorimotor prediction acts at two levels that we will describe in turn: the control of the ongoing action and the simulation of off-line action (Pezzulo, 2011). Let's first consider the control of ongoing action. Feedback motor control allows the modification of ongoing movement by using information from sensory receptors. This type of control is slow and needs to be combined with feedforward processes in order to produce accurate and fluent movements, that require internal models of action. These internal models of action allow the brain to imitate input and output characteristics of motor unit (Kawato, 1999). Two varieties of internal models are classically defined: direct and inverse internal models. Direct internal models allow to predict sensorial consequences of the ongoing action from efference copies of issued motor commands, while inverse internal models calculate motor commands needed to complete the action (Kawato, 1999; Miall & Wolpert, 1996; Wolpert & Ghahramani, 2004; Wolpert, Ghahramani, & Jordan, 1995). Feedforward internal models of action allow thus to generate several hypotheses on sensorial consequences of the ongoing action by the way of direct models acting as a predictor, as well as to select adapted motor program by the way of inverse models acting as a feedforward controller and thus playing a fundamental role in motor learning (Wolpert & Kawato, 1998).

Applied to the use of tablets, interaction between the hand and the digital tactile interface would give rise to a set of afferent and efferent kinesthetic and proprioceptive information (Lederman & Klatzky, 1987) that would differ from those generated through the interaction with pencil on a sheet of paper, as revealed by the work of Alamargot and Morin (2015). These authors demonstrated that, compared to the roughness of a paper sheet, the smoothness of a tablet screen reduces the friction between the pen and the surface of the tablet, which lessens proprioceptive feedback, giving rise to differences in motor execution (higher letter size) and motor kinematics (higher speed of execution) in writing letters, this effect being observed in second and ninth grade students. Similar results were found in Gerth et al. (2016) with preschoolers, second graders, and adults being affected by a difference in friction of the writing surface. However, writing letters on a tablet with finger seems to offer an enriched tactile experience. This facilitating effect of tablets has been clearly demonstrated in the context of writing skills in young children. As a matter of fact, Patchan and Puranik (2016) trained preschoolers aged 3 to 6 years to write three times a week for eight weeks, either by using a pen on paper sheet, or a stylus on tablet, or a finger on tablet. Results showed that using a tablet with fingers was the most efficient set, since it led to more correctly written letters than with stylus on tablet or pen on paper. Authors concluded that tablet's benefits in handwriting learning is linked to afferent and efferent information provided by the direct proprioceptive feedback on the tablet. The direct contact of one's finger on the tablet increased friction with the surface and thus haptic feedback, i.e. additional proprioceptive information. Acting directly on the screen with fingers would then offer a richer set of afferent and efferent sensorial information that could foster sensorimotor prediction of action, facilitating motor skills.

By enhancing sensorimotor prediction through the richness of the haptic information processed, tablets could thus improve motor skills and therefore be of special interest, for example, for writing learning in preschool children (Patchan & Puranik, 2016). Could these beneficial effects

observed for writing skills be extended to creative drawing skills? As it has been explained previously, sensorimotor prediction is made possible through feedforward internal models that create an inner loop in which actual sensorimotor interaction is paralleled and imitated: inner loop is thus a kind of “internalization of external reality” (Pezzulo, 2011, p.87). But internal models can also be activated without any actual sensorimotor interaction. In this case, internal models are detached from the actual sensorimotor activity. When decoupled from any actual sensorimotor interaction, internal models, and the inner loop they create, allow to control off-line action. When ran off-line, internal models which are at the core of the embodied representation proposed by Pezzulo (2011) allow to simulate future motor actions or potential actions without even realizing it (Jeannerod, 1994). The transition from on-line to off-line control of action reveals that the sensorimotor prediction first designed to control on-line action would then give rise to a simulation process involved in higher cognitive processes such as, for instance, motor imagery and creativity. The main particularity of these cognitive processes is that despite their disconnection from sensorimotor real activity, they remain rooted in sensorimotor prediction. Studies investigating motor imagery sustain this proposal. Indeed, it has been demonstrated that the easiness to simulate motor action in children is clearly linked to the richness of the afferent set of information children (Guilbert, Jouen, Lehalle, & Molina, 2013; Guilbert, Molina, & Jouen, 2016) and adolescents (Choudhury, Charman, Bird, & Blakemore, 2007) can refer to although they are not enrolled in a real action.

This process of simulation has been recently proposed to give account for creativity, a cognitive process based on sensorimotor prediction. According to Dietrich and Haider (2015), creative thinking could thus be thought of as a mere evolutive embodied and situated cognitive process rooted in predictive mechanisms of sensorimotor activity. These authors define creativity as a process of generation and evaluation of ideas never thought before, in a trial-and-error basis, relying on the same predictive mechanism as those involved in motor control of action. Most

precisely, the predictive processing used for the motor control of action would be the mechanism allowing the generation of creative ideas. A creative idea would be generated and evaluated in the same way a motor action would be controlled. The main difference with motor control of action, is that creative thinking acts in an unknown space since it concerns ideas not thought before. Thus, Dietrich and Haider (2015) conceive the creative idea as an abstract form of predictive processing ran by internal models, originally used for motor control of action. Direct models allowing the generation of various motor solutions in motor control of action, would likewise allow, in the case of creative thinking, to generate various hypotheses to reach a creative goal. Inverse model acting as a controller and a selection of the most adapted motor solution would allow, in the case of creativity, to select and evaluate the various hypotheses generated. In a drawing situation, the core of the creative drawing would be selected by inverse models as a goal to be reached. This goal would be based on known experience (knowing how to draw a house according to one's typical representation of a house), as well as on an unknown experience in order to generate a new and original idea. Direct models would generate several hypotheses for reaching this goal. Inverse models would be ran to evaluate and select the variation of ideas.

To summarize the theoretical proposals rooted in embodied framework, acting with fingers on a tablet would strengthen internal models of action due to the enrichment of incoming afference information. This would have two consequences: it would facilitate the prediction of sensory information necessary for the on-line control of the graphic action. It would also sustain the simulation of off-line action and thus facilitate the process of creativity by generating a wide range of motor actions to be executed.

Currently, no research has directly addressed the question of a possible link between direct fingertip feedbacks on tablet and creativity. However, various studies have investigated whether tablets could constitute a useful medium for drawings. Picard, Martin, and Tsao (2014)

investigated whether drawings differ qualitatively when executed on tablet with finger and on paper with a pen. They invited children aged 5-6 and 7-8 to produce “the best drawing of a house you can” on a tablet with finger and on paper with a pen. Quality of drawings was assessed by mean of a graphical scale developed by Barrouillet, Fayol, and Chevrot (1994) which measured how many drawing elements figuring on a house were realized. Results showed that houses drawn with pen on paper were richer, i.e. contained more elements, than the ones made on tablet with finger. The authors concluded to a facilitator effect of pen on paper use for drawing a house and stated against tablet benefits on drawings. However, they hypothesized that the facilitator effect of the pen could be related to a proximal-distal motor control maturation. They suggested that the poorer graphic performance observed in finger drawing would be the consequence of a difficulty for children to shift from a distal flexion/extension of the fingers involved in pen control to a more proximal control involving elbow and shoulder in finger drawing movements. Benefits of the pen for drawing skills could thus be specific to the young age of the population studied in this research.

The present study was aimed at determining if finger drawing on tablets can be beneficial for generating originality in drawings produced by adolescents aged 13-14. This age was chosen in order to avoid the proximal-distal age-dependent effect reported by Picard et al. (2014), since adults' performance in arm movement control is approached by 10-11 years of age (Chiappedi et al., 2012). Moreover, studies have reported an improvement of off-line motor control of action generated through internal models of action, as it is the case for motor imagery, which is considerably improved due to an increase in visual and proprioceptive information integration (Choudhury et al., 2007). Since creativity is conceived as a predictive processing rooted in sensorimotor control of action (Dietrich & Haider, 2015), the age of 13-14 years is suited to the goal of the present study.

We adapted our experiment from Picard et al.'s (2014) task by asking adolescents to draw a house with finger and stylus on tablet and with pen on paper. House drawing having been used in other drawing tasks with adolescents (Picard & Boulhais, 2011; Picard & Gauthier, 2012), proposing this topic to adolescents seemed relevant. However, contrary to Picard et al. (2014) who considered the number of elements in the drawings executed on tablet and on paper, we elaborated a rating scale to account for the originality of the drawings (details on this scale are presented in the Method section). This originality scale was inspired by Karmiloff-Smith (1990) in which she reported several types of changes operated between the drawing of something that exists and the drawing of something that doesn't exist. Each adolescent was invited to produce these drawings under two different instructions. They were asked to draw a house and to draw a house presenting something never seen before, that is a house with originality. For each adolescent, we compared originality in productions of a house drawn on tablet with stylus or with finger, or with pen on paper, to a house without any originality figured by a prototypical representation of the house. In accordance with the theoretical model of embodied representations used for creativity process (Dietrich & Haider, 2015; Pezzulo, 2011), it was expected that drawing with finger on tablet would lead to increase originality in drawings compared to those produced on the same device with a stylus or on paper with a pen. No differences were expected between drawings produced with a stylus on tablet or a pen on paper.

2. Method

2.1. Participants

Twenty-one voluntary adolescents aged 13-14 (mean age = 13 years, 7 months; SD = 5 months, 19 days) took part in the study. They were recruited from a 9th grade of a junior high school located in Normandy, France. They were enrolled in the study after receiving their written

inform consent as well as their parent's written authorization. No medical or paramedical issue were diagnosed for these teenagers.

2.2. Materials

Digital drawings were made on a Microsoft Surface Pro 4 tablet, 12.3" screen and 2736 x 1824 px resolution, with a Microsoft Surface Pen measuring 144 x 9.5 x 10.2 mm. Drawings were made on an app designed in our Laboratory, presenting a white surface on which it can be drawn with stylus or finger by tracing only black traits. Erasing function was not enabled on the app nor in the pen and paper condition. Paper sheets measuring the same size as the screen (260 x 175 mm), and a black pencil were used.

2.3. Procedure

Adolescents were observed individually in a quiet room of the junior high school. They sat down in front of a table (700 x 500 x 750 mm) where the tablet was placed. Each adolescent had to produce three original drawings of a house with finger on tablet, with stylus on tablet and with pen on paper and an unoriginal drawing of a house with a pen on paper. In order to counteract the difficulty and fatigability of drawing three original houses in a same session, we decided to cut the experimental procedure in two sessions based on the support used. In the first session, half of the adolescents produced two original drawings on the tablet after reading the following instruction: "Imagine that an architectural firm wants to offer you a job. They ask you, for your first job, to draw the more original house as possible with your finger thanks to a tablet. Following the production of this drawing, they ask you to draw another original house using the stylus". Once a first drawing was produced, it was removed before starting the execution of a new one. The other half of adolescents received the same instruction in a reverse order: they had first to draw an original house using a stylus and then using their finger. During

the instruction reading, the experimenter stood near the adolescent to help him/her in the understanding of the task if he/she needed to. The second session took place two months later. Placed in the same condition, each adolescent was asked to draw with a pen on paper, “a normal, simple house” referring to the unoriginal house and a house “the more original as possible”. Note that “normal” and “simple” were added to the instruction of the unoriginal drawing to be sure adolescents would make a distinction between the two conditions in order to draw a house without any kind of originality, referring to their own prototypical representation of what an existing house is. Unoriginal drawings made on paper with a pen were used to control for interindividual prototypical representations of a house drawing. The logic was to consider as being original in the drawings, any original modification in comparison of a prototypical house (according to the scale) that was not present in the drawing of a unoriginal house. A delay of two months between sessions was chosen to prevent adolescents’ weariness or training effect in original drawing which could both affect their drawings made on paper. This second session included two different instructions (original and unoriginal) but with a same support (pen on paper). Since the unoriginal drawing was used as a control to assess originality in original drawings, and because Karmiloff-Smith (1990) did not observe instruction order between drawings of something that exists and something that doesn’t exist, we decided to randomize the order of presentation of the two conditions in our experiment.

2.4. Coding

A total of 84 individual electronic (42) and paper (42) drawings were collected for analysis. The core elements coded in each drawing were inspired from those presented in the rating scale created by Barrouillet et al. (1994) in order to identify, in a same age group, prototypical elements represented in the drawing of a house. From the drawings of a house realized by children aged from 3 to 11 years, 21 items were represented in more than 30% of the drawings and were thus retained. These items concerned 11 following elements of the house: base, roof,

windows, door, panes, path, chimney, shutters, curtains, attic room and door handle. However, using this scale to assess the best house drawn on tablet and on paper by children aged 5-6 and 7-8 years old, Picard et al. (2014) showed that, whatever the support used (paper or tablet), path, chimney, curtains, attic room and shutters were drawn in less than 50% of the drawings, which raises the question of the definition of these items as original or prototypical. To our knowledge, this question remains unsolved. Therefore, we decided to not consider these 5 elements for the analysis of the drawings. It means that, although not present in the prototypical house, adding these items in the original drawing was not rewarding any points regarding the originality rating scale. In the same way, because Barrouillet et al. (1994) didn't give precise indications except for its presence, door handle was not considered as a core element to be coded in the rating scale, although its prevalence was about 70% in digital drawings (Picard et al., 2014). A total of 5 core elements (base, roof, windows, door, and panes) were thus considered in our scale.

These 5 core elements were used to define a prototypical house (Figure 1) corresponding to the description of elements in the scale of the house drawing proposed by Barrouillet et al. (1994). As described in Barrouillet et al. (1994), the prototypical house was defined as follows. It included a rectangular base (at least 3 rectilinear segments) with a rectangular door (at least 3 rectilinear segments) at its bottom center, and two squared windows upstairs, one on the left, one on the right, horizontally aligned and with no side of the base or the roof considered as the 4th segment. Windows proportions should be between 1/4 and 1/6 of the height and width of the facade, and panes represented as a cross inside each window. On top of the rectangular base should be a triangular or trapezoidal roof, measuring the same width than the base.

In addition to the description of the prototypical house according to Barrouillet et al. (1994), details were added to be able to assess modifications more precisely. Therefore, we precised door's size as being proportioned with base's size, such as the door couldn't be longer or larger than the base, as well as panes couldn't be proportionally longer or larger than window's height

and width. Because our study aimed at tracking originality modifications in the house rather than developmental representation of a prototypical house, the bottom of the surface (paper or tablet) could be considered as the 4th rectilinear segment of the base, as well as the bottom of the base could be considered to complete the 4 rectilinear segments for the door, in the opposite of Barrouillet et al. (1994).

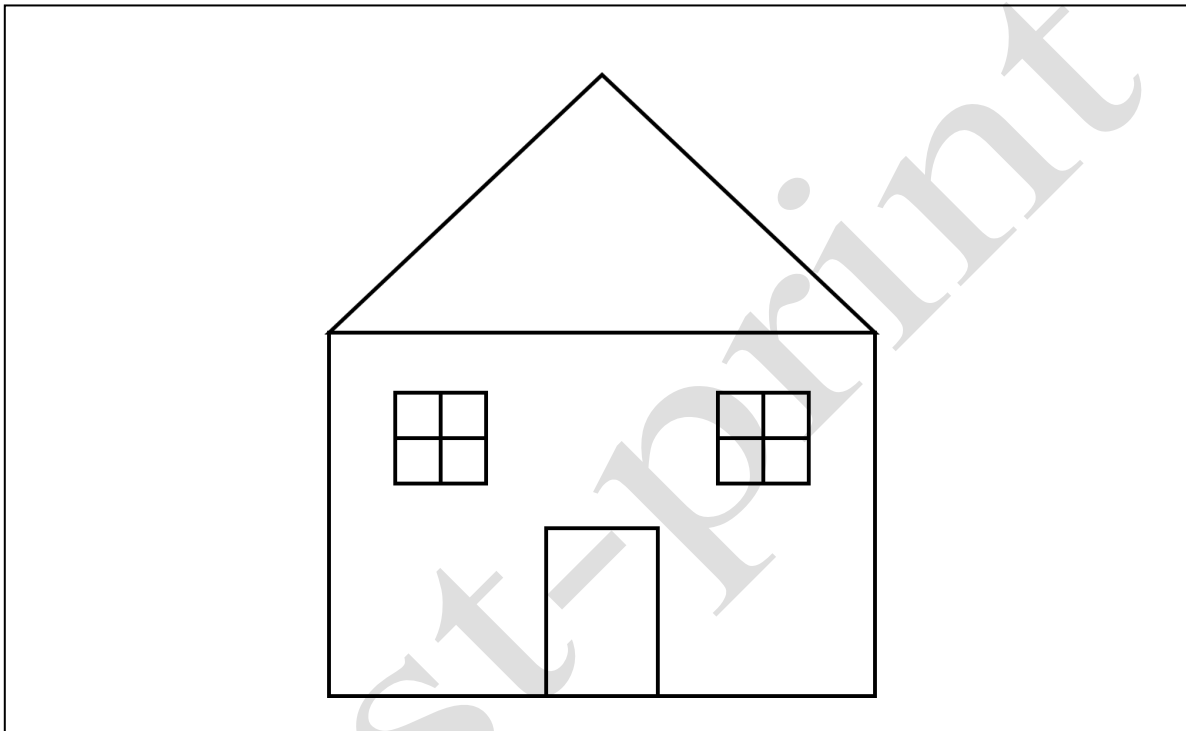


Figure 1. Example of a prototypical drawing of a house according to the 5 items (base, roof, windows, door, and panes) considered in our scale.

Figure 1. Exemple d'un dessin prototypique d'une maison selon les 5 items (base, toit, fenêtres, porte, et vitres) considérés dans notre échelle.

This prototypical house was used to assess any original graphical changes observed in the drawings produced by the adolescents according to the seven categories of graphical changes observed by Karmiloff-Smith (1990) for the drawing of something (house, man or animal) that does not exist:

- addition and deletion of elements (e.g. 3 doors instead of 1, or no door at all);

- modification operated on the shape of elements (e.g. a circular roof instead of a triangular roof);
- modification operated on the size of elements (e.g. a window two times bigger than the house's roof);
- insertion of new elements (e.g. towers added to house's base);
- position, orientation, and perspective modifications of elements or the whole drawing (e.g. a door and window inverted, or the house placed upside down);
- cross-conceptual categories modifications of the whole drawing (e.g. an animal-shaped house);
- modifications operated on the shape of the whole drawing (e.g. a circle-shaped house).

Note that the first category, "addition of new elements" refers to the simple replication of an already existing element (e.g. 3 doors instead of 1), while the fourth category "insertion of new elements" refers to the addition of something new about an element (e.g. towers added on the base).

These seven categories considered as well global modifications occurring on the whole drawing as local modifications that concerned isolated elements of the drawing. Local modifications concerned the 5 core elements of a house drawing. As an exception, the category "insertion of new elements" included in addition to the 5 core elements, an item "others", in order to award every new idea added by the adolescents, even if it concerned elements drawn outside of the house (for example, flying fishes around the house).

For each modification operated on elements (local modifications), 0.5 point was assigned. Each global modification was awarded the double, i.e. 1 point, since it concerned larger modifications than those consecutive to a local element modification. Only one exception to this was for "position, orientation, and perspective" category that was rated 1.5 points since it concerns simultaneously local and global modifications. For example, "position change" would

necessarily concern at least 2 elements (let's say, exchanging the position of windows and door) which would result in a strongly increased originality score. This category was awarded 0.5 point for a local modification, no matter the number of elements, and 1 point for a global change concerning the whole drawing (for example, upside-down house).

Table I sums up the characteristics of the rating scale. Each drawing could be rated from 0 to 14. Note that the originality scale covers large possibilities of modifications such that adolescents probably won't make use of all of them in one drawing.

Table I. Rating scale used to assess originality in drawings

Table II. Echelle de cotation utilisée pour évaluer l'originalité des dessins

| Graphical change | Definition | Type of change | Awarded points (min-max) |
|--|--|-------------------------------|--------------------------|
| Deletion/addition Fig. 2 & 3 | Element of a prototypical house (base, roof, windows, door, and panes) replicated or deleted | Core element | 0 – 2.5 |
| Shape of elements Fig. 3 | Element (base, roof, windows, door, and panes) whose shape was different from the prototypical house | Core element | 0 – 2.5 |
| Size of elements Fig. 4 | Element (base, roof, windows, door, and panes) whose size was different from the prototypical house | Core element | 0 – 2.5 |
| Insertion of new elements Fig. 5 | New element (at the level of base, roof, windows, door, panes or others) which were not present on prototypical house | Core element | 0 – 3 |
| Position, orientation, and perspective Fig. 6 | Elements (base, roof, windows, door, and panes) and/or the whole drawing different in position, orientation, and perspective from the prototypical house | Core element and on the whole | 0 – 1.5 |
| Cross-conceptual category | Whole drawing presenting insertions crossed with other conceptual | On the whole | 0 – 1 |

| | | | |
|-----------------------------|---|--------------|--------|
| Fig. 7 | categories (trees, animals, technology, ...) | | |
| Form of the whole Fig. 8 | Drawing whose whole form was not prototypical-house-like shaped | On the whole | 0 – 1 |
| | | TOTAL | 0 - 14 |

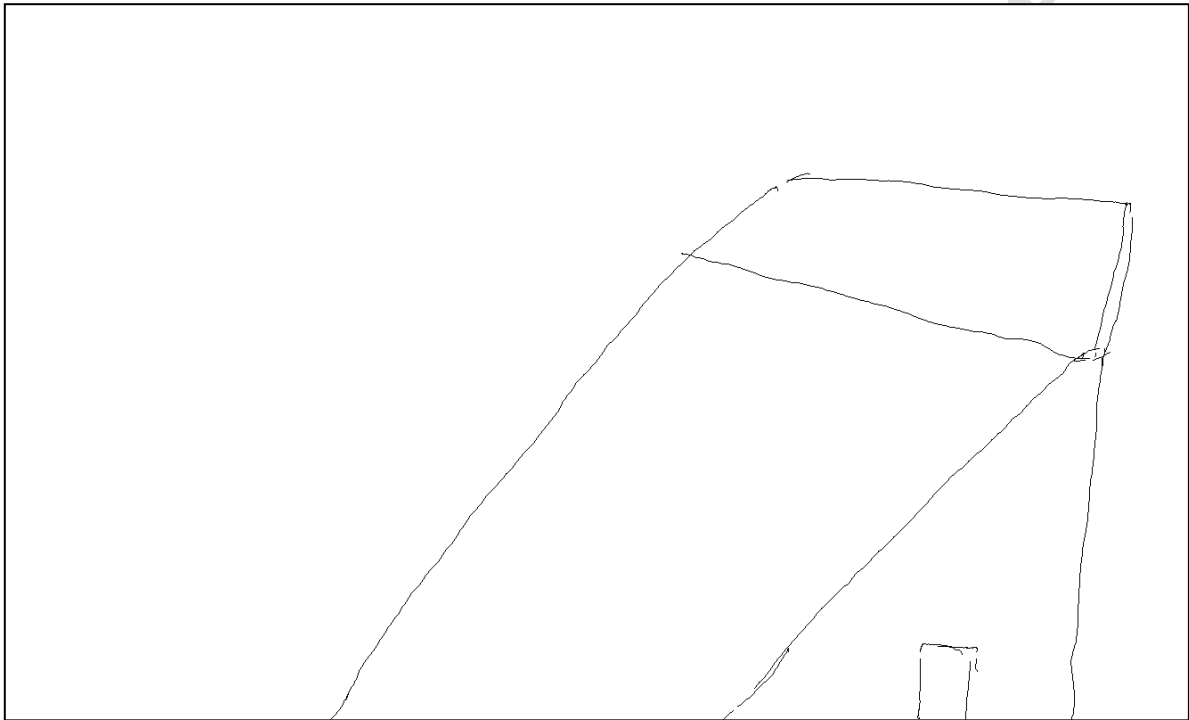


Figure 2. Example of deletions in finger drawing on tablet: compared to the prototypical house, windows have been deleted.

Figure 2. Exemple de suppressions dans un dessin réalisé au doigt sur tablette : comparé au dessin prototypique, les fenêtres ont été supprimées.

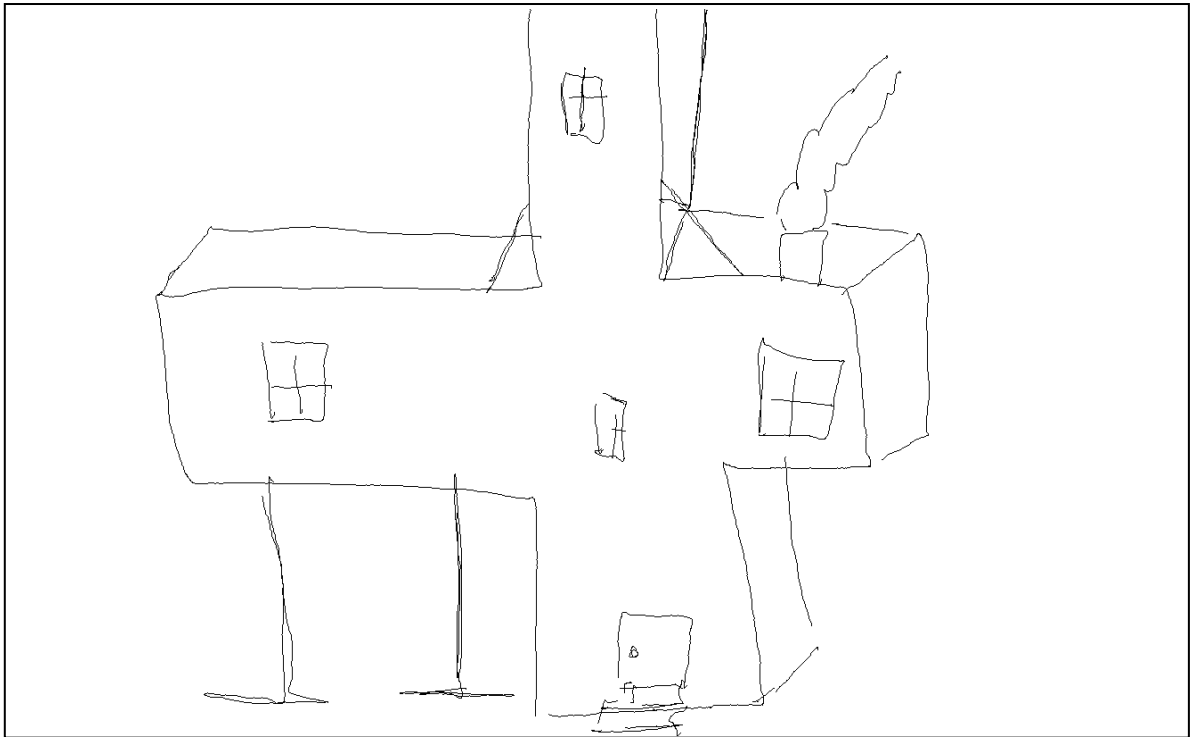


Figure 3. Example of additions and shape modification of elements in finger drawing on tablet: compared to the prototypical house, windows have been added (4 instead of 2) and the shape of the base has been modified (crossed form instead of a rectangular form).

Figure 3. Exemple d'additions et de modifications de forme des éléments dans un dessin réalisé au doigt sur tablette : comparé au dessin prototypique, les fenêtres ont été ajoutées (4 au lieu de 2) et la forme de la base a été modifiée (forme de croix au lieu d'une forme rectangulaire).

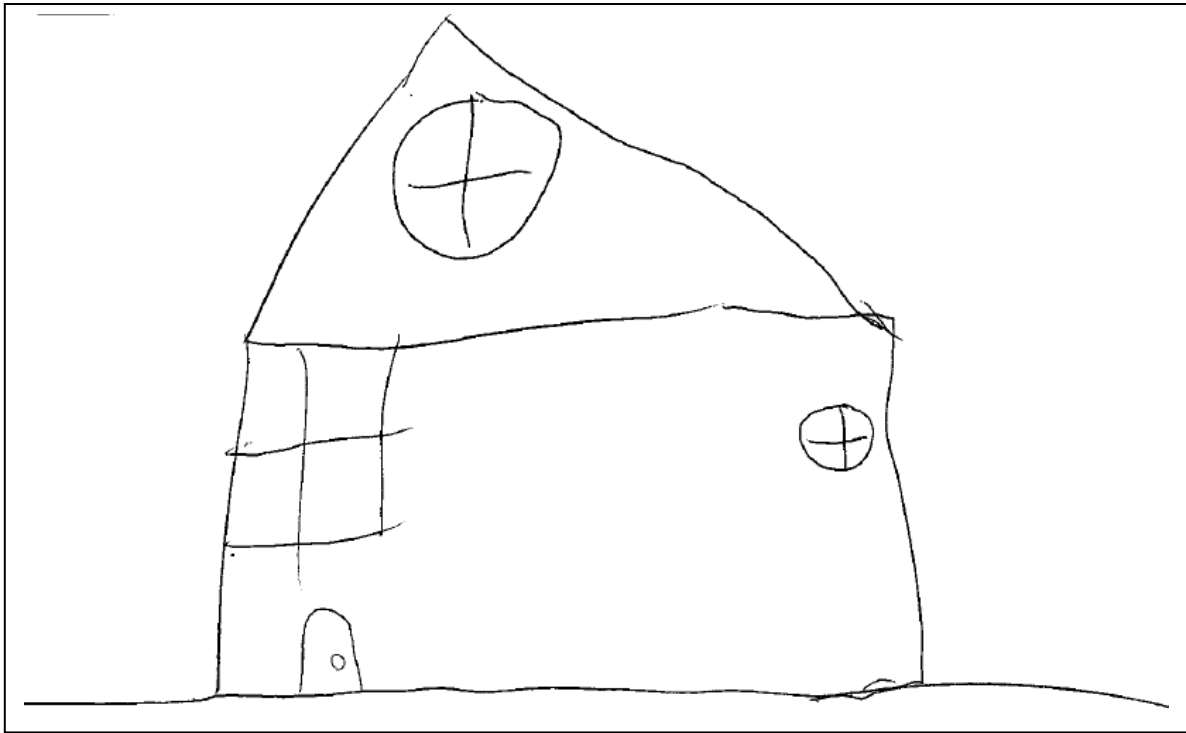


Figure 4. Example of size and shape modifications on elements in pen on paper drawing: compared to the prototypical house, the size of a window (on the left) has been modified, and shape of the other window (on the right) has been modified.

Figure 4. Exemple de modifications de la taille et de la forme des éléments dans un dessin réalisé au stylo sur papier : comparé à la maison prototypique, la taille d'une fenêtre (sur la gauche) a été modifiée, et la forme de l'autre fenêtre (sur la droite) a été modifiée.

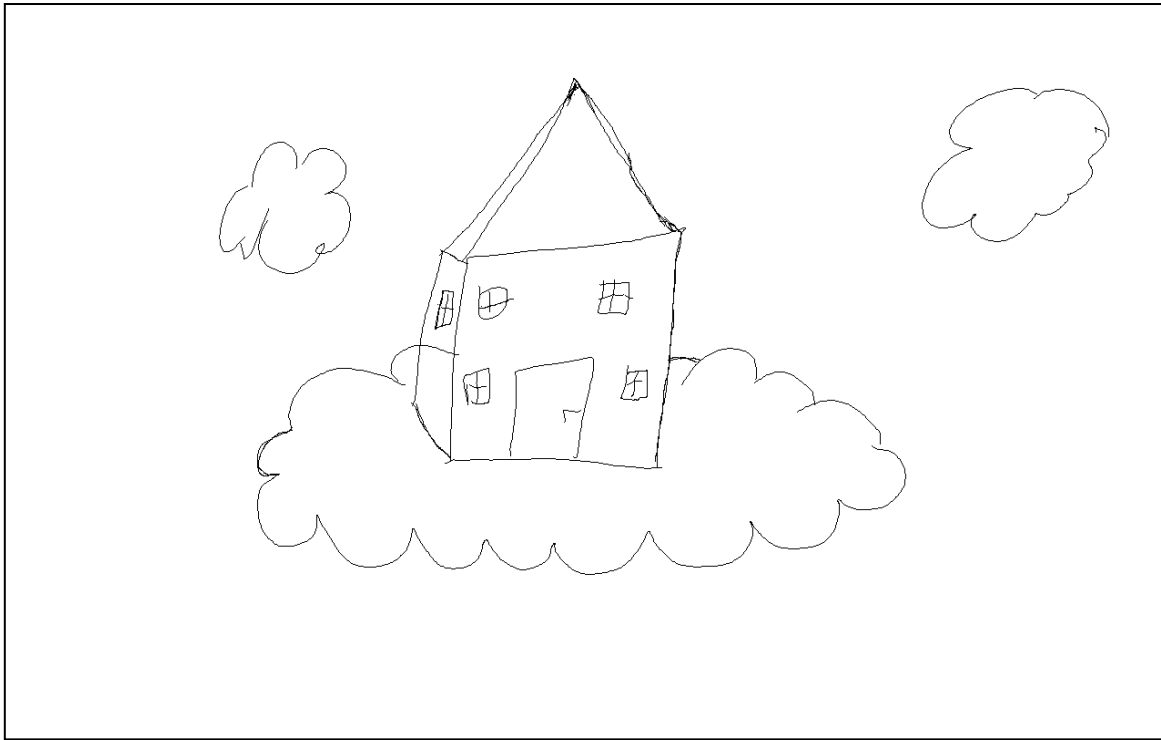


Figure 5. Example of insertion of new elements in stylus drawing on tablet: compared to the prototypical house, clouds have been added to the drawing (“others” element).

Figure 5. Exemple d'insertion de nouveaux éléments dans un dessin réalisé au stylet sur tablette : comparé au dessin prototypique, les nuages ont été ajoutés au dessin (élément « autres »).

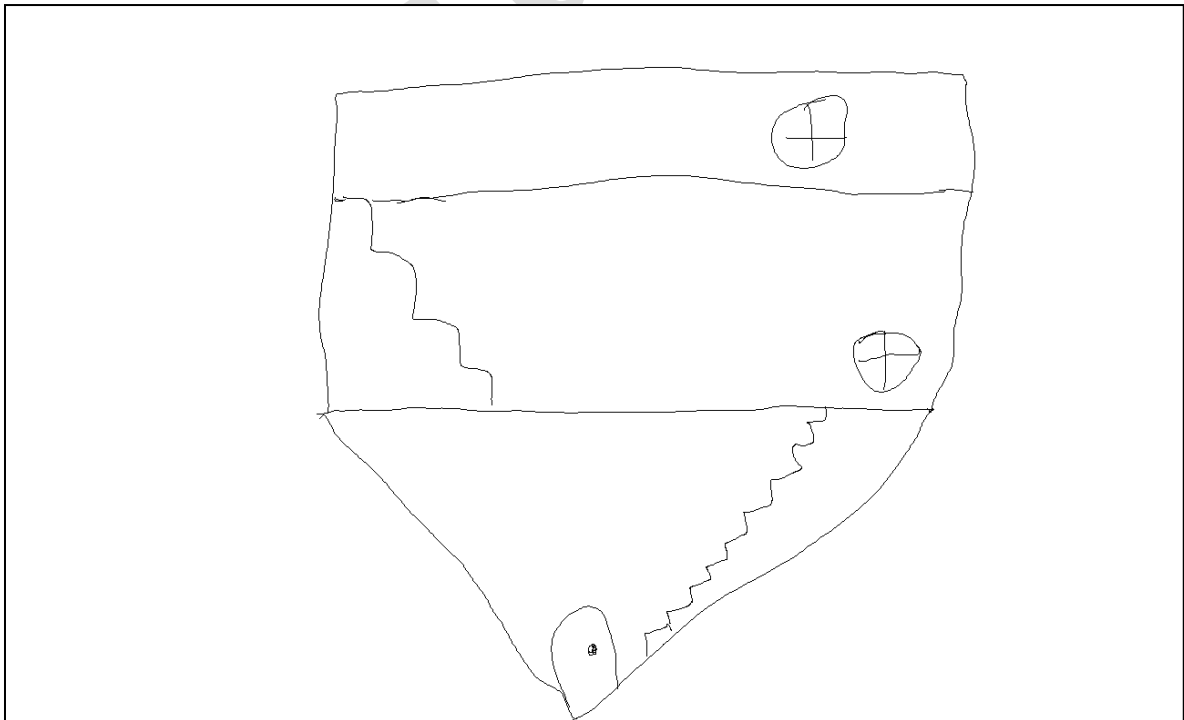


Figure 6. Example of global position modification in stylus drawing on tablet: compared to the prototypical house, position of the whole house has been changed and placed upside-down.

Figure 6. Exemple de modification de position globale dans un dessin réalisé au stylet sur tablette : comparé au dessin prototypique, la position de l'ensemble de la maison a été changée en la retournant.



Figure 7. Example of cross-conceptual modification in pen on paper drawing: compared to the prototypical house, this drawing includes cross-category insertion such that components of different categories (tree and house) appear in the drawing.

Figure 7. Exemple de modification inter-conceptuelle dans un dessin réalisé au stylo sur papier : comparé à la maison prototypique, ce dessin inclut une insertion inter-catégorie de telle sorte que les composants propres à différentes catégories (arbre et maison) apparaissent dans le dessin.

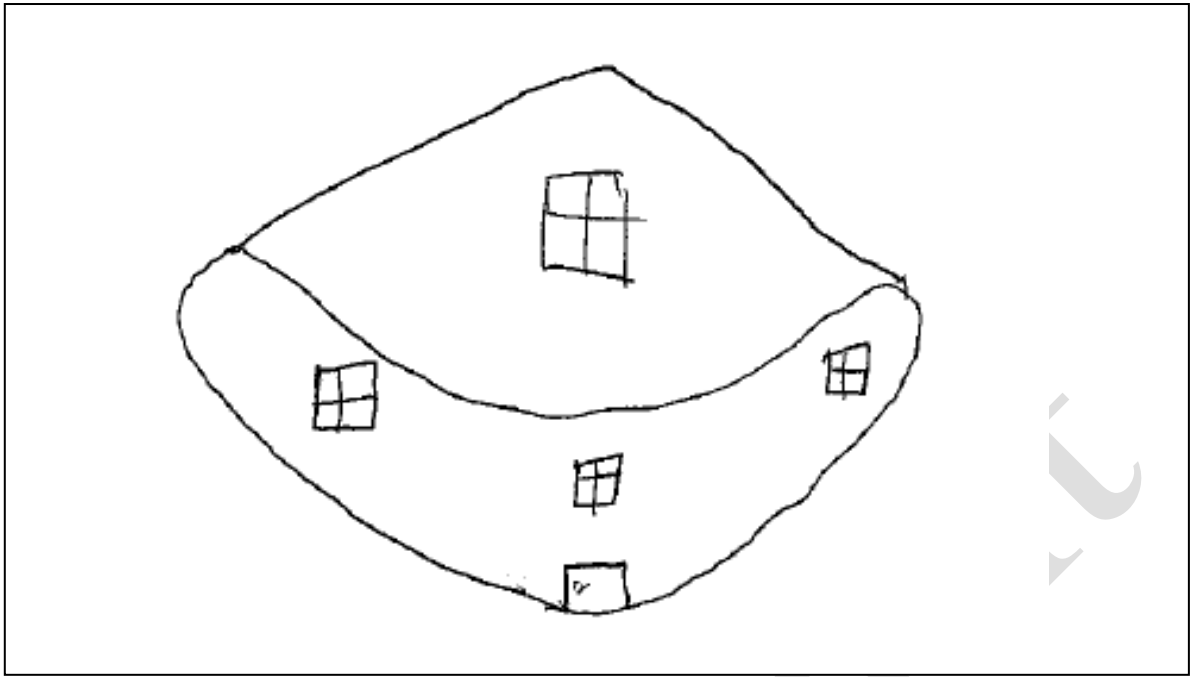


Figure 8. Example of modifications operated on the form of the whole in pen on paper drawing: compared to the prototypical house, the whole drawing was not prototypically house-like shaped.

Figure 8. Exemple de modifications opérées sur la forme générale dans un dessin réalisé au stylo sur papier : comparé à la maison prototypique, le dessin dans son ensemble ne correspondait pas à la forme d'une maison prototypique.

Four originality scores were thus calculated using the rating scale (Table I), one for each original drawing executed on tablet with finger, with stylus, and on paper with a pen and one for the unoriginal drawing executed on paper with a pen. For each adolescent, originality score of each original drawing made on tablet with finger and stylus and on paper with a pen was defined by the sum of originality points attributed to the original drawing in comparison of the prototypical house, minus the originality points obtained for the same items in the unoriginal drawing made on paper. Therefore, for each production of an adolescent, every point awarded to items that were already considered by the scale as original on the unoriginal drawing made on paper were thus deleted from all original drawings. This allowed to control adolescent's subjective bias of what is or is not considered as originality. This procedure of control is devoted to avoiding a bias in the calculation of originality score which could be artificially increased,

by considering as original elements presented in the unoriginal house drawing. For example, as shown in Figure 9, if an adolescent drew circle windows in the original house instead of rectangular ones as mentioned in the prototypical house, no points were awarded since circle windows were also drawn in the unoriginal house. It allows to filter in original drawings, elements that differ from unoriginal drawings. The calculation of originality score in drawings was thus consistent with the definition of originality, that is, the capacity to assess and select a novel idea among all other own ideas, depending on the acquired knowledge, i.e. what adolescents know about what is a “simple, normal” house (Lubart & Georgsdottir, 2004; Runco, 1991).

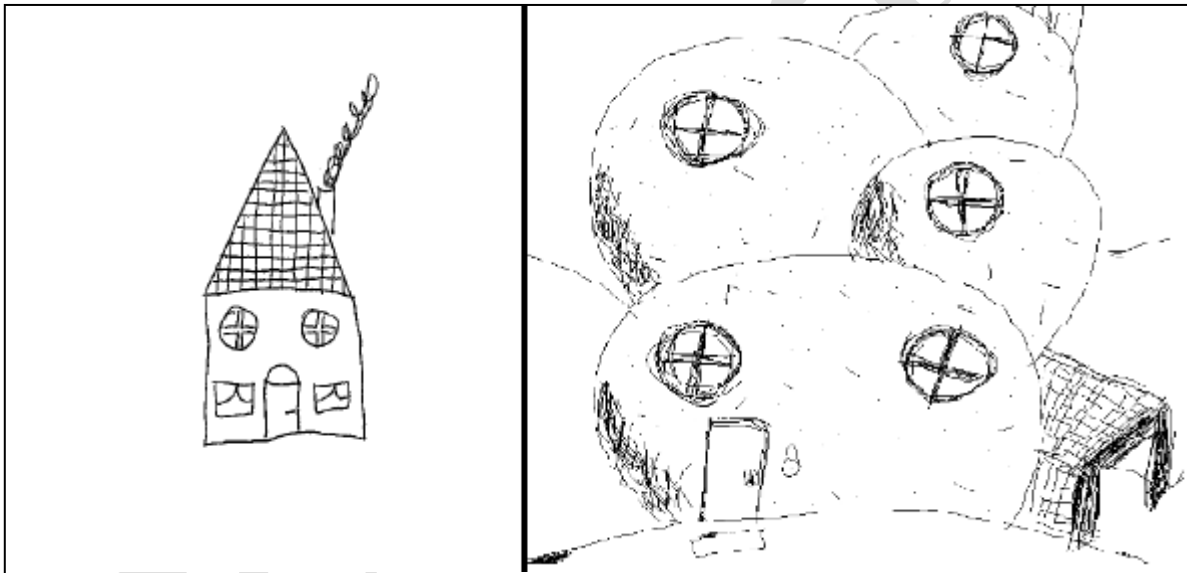


Figure 9. Example of coding of the unoriginal drawing with a pen on paper (on the left) compared to original drawing with finger on tablet (on the right) for a same adolescent: 0.5 point initially awarded for circle windows in the original drawing were withdrawn from originality score.

Figure 9. Exemple de cotation d'un dessin non-original réalisé au stylo sur papier (à gauche) comparé au dessin original réalisé au doigt sur tablette (sur la droite) pour un même adolescent : 0,5 point attribué initialement pour les fenêtres rondes dans le dessin original a été retiré du score d'originalité.

2.5. Data analysis

To make sure that instructions were well understood, an interrater agreement score was calculated among original and unoriginal drawings from all supports. Two naive observers were asked to categorize the drawings as being original or unoriginal. Cohen's Kappa showed a strong inter-reliability agreement between the two raters ($K = .855$), showing that even if originality can be quite subjective, the instruction given to adolescents led them to produce original drawings.

Prior to any statistical analysis, normality (Shapiro-Wilk test) and sphericity of variance (Mauchly's test) of the distributions of originality scores were tested in order to control that parametric analysis could be used to evaluate originality performances in drawings. The tests confirmed the Gaussian nature of data of variances for originality scores of productions realized with finger on tablet ($W = .93, p = .17$), with stylus on tablet ($W = .97, p = .80$) and with pen on paper ($W = .91, p = .06$). The sphericity condition was also met, as assessed by Mauchly's Test of Sphericity, $p = .168$. Originality scores of drawings made by each adolescent on tablet with finger, stylus, and on paper with a pen were thus compared by mean of a repeated measures ANOVA with tool presentation order (01: finger then stylus; 02: stylus then finger) as between-group factor, and tool used (finger on tablet versus stylus on tablet versus pen on paper) as within-group factor. In addition, we performed Cochran analyses to investigate whether occurrence of graphical transformations varied according to the drawing conditions.

3. Results

Analyses were conducted in order to determine whether each category of transformation was equally used when adolescents drew original house with finger, stylus, or pen. Using Cochran's Q test, we carried out a first analysis to determine whether, all elements of the house being confounded, a drawing condition favored more specifically a category of transformation. Results revealed that, although the 7 categories of transformation were observed in the three

drawing conditions (Table II), only two out of the seven considered were not equally observed across the three drawing conditions. Adolescents modified more the size of elements when drawing with finger on tablet (46.67%) and with stylus on tablet (37.14%) than when drawing with pen on paper (22.86%), $Q(2) = 17,92$; $p = .00013$. Adolescents made more insertion of new elements for drawings made on tablet with finger (26.98%) and with stylus (26.19%) than for drawings made on paper with a pen, (16.67%), $Q(2) = 8,26$; $p = .016$.

We then examined occurrence of each category of transformation for each element of the house (see Table II) according to the drawing conditions (finger, stylus, and pen). Among the 7 categories of transformation, the only significant change was observed for the size of element concerning the door, $Q(2) = 6.5$, $p < .03$. As can be seen in Table II, the size of the door was less frequently changed in drawings made with pen on paper (5%) compared to drawings made with finger on tablet (38%) or with stylus on tablet (29%). No other significant differences were observed, revealing a comparable occurrence of all other categories of transformation for each drawing condition.

Table II. Occurrence (percentage) of each item of originality scale as a function of drawing condition

Table II. Occurrence (pourcentage) de chaque item de l'échelle d'originalité en fonction de la condition de dessin

| | Finger | Stylus | Pen |
|--------------------------------------|--------|--------|-------|
| I - Deletion or addition of elements | | | |
| 0 - All elements confounded | 34,28 | 38,09 | 33,33 |
| 1- Base | 19 | 24 | 10 |
| 2- Roof | 38 | 33 | 29 |
| 3- Windows | 71 | 76 | 71 |
| 4- Doors | 5 | 14 | 19 |
| 5- Panes | 38 | 43 | 38 |
| II - Shape of elements | | | |
| 0 - All elements confounded | 39,04 | 28,57 | 34,28 |
| 1- Base | 52 | 52 | 48 |

| | | | |
|---|-------|-------|-------|
| 2- Roof | 43 | 33 | 48 |
| 3- Windows | 67 | 38 | 52 |
| 4- Doors | 24 | 5 | 14 |
| 5- Panes | 10 | 14 | 10 |
| III - Size of elements | | | |
| 0 - All elements confounded* | 46,67 | 37,14 | 22,86 |
| 1- Base | 67 | 57 | 48 |
| 2- Roof | 38 | 24 | 19 |
| 3- Windows | 71 | 52 | 33 |
| 4- Doors* | 38 | 29 | 5 |
| 5- Panes | 19 | 24 | 10 |
| IV - Insertion of new elements | | | |
| 0 - All elements confounded* | 26,98 | 26,19 | 16,67 |
| 1- Base | 52 | 57 | 43 |
| 2- Roof | 43 | 33 | 14 |
| 3- Windows | 14 | 14 | 10 |
| 4- Doors | 19 | 19 | 5 |
| 5- Panes | 0 | 0 | 0 |
| 6- Others | 33 | 33 | 29 |
| V - Position, orientation and perspective modifications | | | |
| 0 - All elements confounded | 14,28 | 11,9 | 4,76 |
| 1- On the whole | 0 | 5 | 0 |
| 2- On elements | 29 | 19 | 10 |
| VI - Cross-conceptual categories modification | | | |
| On the whole | 29 | 29 | 24 |
| VII - Form of the whole | | | |
| On the whole | 43 | 33 | 38 |

(*item for which a significant change was observed between drawing with finger, stylus or pen with Cochran Q test)

(*item pour lesquels un changement significatif a été observé entre les dessins réalisés au doigt sur tablette, au stylet sur tablette, ou au crayon sur papier, avec le Q de Cochran)

An ANOVA was performed in order to determine whether originality score varied according to drawing conditions. The ANOVA did not reveal a significant effect of the order of presentation of the tool used on tablet (01: finger then stylus; 02: stylus then finger), $F(1, 19) = .69$ $p = .42$. The interaction between tool used and order of presentation of the tool was not significant, $F(2, 38) = .38$ $p = .68$. As shown in figure 10, the ANOVA revealed a significant

effect of the used tool (finger on tablet, stylus on tablet, pen on paper) on originality scores, $F(2, 38) = 13.98$, $p = .00003$, $\eta_p^2 = .42$, with originality score being higher for drawings produced on tablet with finger ($M = 4.05$, $SD = 1.82$), than with a stylus ($M = 3.52$, $SD = 1.82$), drawings produced with a pen on paper giving rise to the lowest originality score ($M = 2.81$, $SD = 1.78$). Post hoc Bonferroni test revealed that original scores for drawings produced with finger on tablet differ significantly from original scores for drawings produced with a pen on paper, $p = .00016$ (Figure 10). Scores for drawings on tablet with a stylus also differed from scores for drawings on paper, $p = .012$. Original scores of drawings produced with finger on tablet did not differ significantly from drawings produced with a stylus on tablet, $p = .093$.

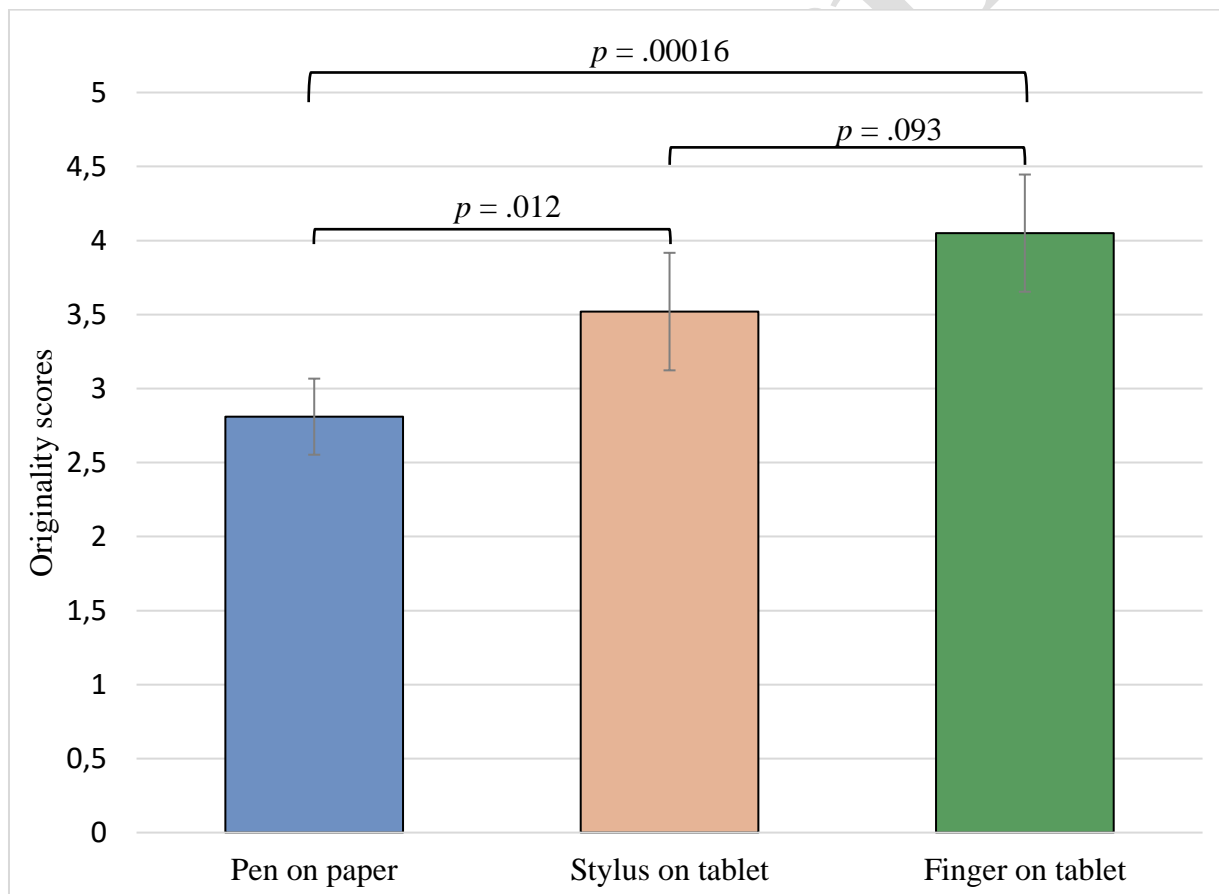


Figure 10. Originality scores (mean and standard errors of mean) according to the drawing device (pen on paper, stylus on tablet, finger on tablet).

Figure 10. Scores d'originalité (moyenne et erreur standard de la moyenne) en fonction du dispositif utilisé (stylo sur papier, stylet sur tablette, doigt sur tablette).

4. Discussion

The present study was aimed at determining if the use of tablets could be beneficial for original drawings produced by adolescents aged 13-14. Creativity being conceived as a predictive processing rooted in sensorimotor control of action, we expected that using tablet with finger would expand drawing originality, that is the novelty of creative ideas in the drawing. More precisely, thanks to an increase of proprioceptive afferent information, internal models for the on-line control of action would be enriched leading to an improvement of simulation process used for the creative process. This effect was not expected for drawings made on tablet with a stylus because it was predicted, in the opposite of finger use, to lessen proprioceptive feedbacks (Alamargot & Morin, 2015). Results were obtained on a small sample of adolescents and must therefore be analyzed with caution. Results revealed that the production of original drawings led to a variety of graphical modifications observed as well when adolescents drew with finger on tablet, with stylus on tablet and with pen on paper. In other words, even if modification of the size of elements and insertions of new elements were more used when drawing on tablet than on paper, each drawing condition was equally likely to induce the seven categories of modification we scored. In spite of it, and in accordance with our main hypothesis, finger drawing on tablet led to a higher originality score than drawings made with a pen on paper. However, drawing with a stylus also led to higher originality score compared to drawings made with a pen on paper. Originality score obtained from drawings made with finger on tablet did not differ from the ones made with stylus on tablet. Each result is discussed in turn.

4.1. The positive effect of drawing with finger on a tablet: a difference with pen drawing on a paper

In line with our main hypothesis, adolescents were more original when drawing on tablet with their finger rather than on a paper sheet with a pen, since originality scores were higher for

drawings made with finger on tablet than for drawings made with pen on paper. This result contrasts with those reported by Picard et al. (2014) who recorded lower performances with finger on tablet than with pen on paper when children were asked to draw “the best house as possible”. Two reasons could explain this difference. On a first place, considering the younger age of the participants involved in the study of Picard et al. (2014), the poorer results obtained by children aged 5-6 and 7-8 years when drawing with fingers could be related to the motor strategies involved by the task. As a matter of fact, Picard et al. (2014) suggested that children had some difficulties when drawing with fingers because it involves elbow and shoulder movements which are less mature than movements of the wrist involved when drawing with a pen. In accordance with the work of Chiappedi et al. (2012) showing that upper limb motor trajectories reach adult performance by the age of 11, it could be suggested that by 13/14 years, wrist, elbow, and shoulder movements can be performed with a comparable accuracy. On a second place, the difference observed between the two studies could be a consequence of the degree of mastery of touchscreen devices. Picard et al. (2014) suggested that training tablet use for the children observed in their study may have countered negative results obtained in the situation of finger drawing. The question of training may not concern teenagers in the same way. As reminded in the introduction section, mobile touchscreen devices such as smartphones and tablets are well-known among teenagers of occidental society since up to 84% of 13-14 years old adolescents make use of it in their daily life (Rideout, 2016). But the use of tablets may not be mastered by children aged 3 to 8 years for whom mobile devices are used once a day for only 27% of 2 to 4 years and 37% of 5 to 8 years (Rideout, 2017). A training session may thus be necessary for children before evaluating how they performed with these devices. Patchan and Puranik (2016) observed that when 3 to 6 years old children were trained to write on tablet, they performed better when writing with finger than with a stylus or a pen on paper.

Authors concluded that when discharged from pen control, young children learned to write more easily thanks to an enrichment of sensorial feedback when writing with finger on tablet. In the present research, it can be concluded that the tablet's positive effect on originality in drawings made with finger highlights the enrichment of tactile information in the generation of original traces. Compared to children aged 5-6 and 7-8 years, adolescents do not only present mature arm movements, or higher familiarity with touchscreen use, they are also in a different period of motor control. Since the seminal work of Hay (1978), it is now established that, by 9/10 years, children are able to integrate proprioceptive and visual information leading to the development of feedforward motor control of action. In consequence, by 13 years, internal models for the control of on-line action are well developed (Choudhury et al., 2007; Smits-Engelsman, & Wilson, 2013). Drawing with finger increases the proprioceptive information used for the formation of internal models of action. According to our hypothesis, this feedforward motor control ensures prediction possibilities involved in creativity (Dietrich & Haider, 2015). Thus, the positive effect of finger drawing on tablet in a creative task may be explained by a richer mobilization of the simulation process of actions as a consequence of richer proprioceptive information, allowing to generate a wide range of motor actions to be executed. The positive effect of drawing with finger on tablet thus confirms the link between on-line control of action (with proprioceptive feedback) and the simulation process linked to creativity.

4.2. The stylus effect in original drawing

Surprisingly, results revealed that acting with a stylus on a tablet also enhanced originality. When drawings were performed with a similar tool on a different surface (a pen on paper), higher originality scores were observed for drawings made with stylus on tablet compared to those made with a pen on paper. We did not expect this effect, based on previous studies

reporting a negative effect of writing on tablet with a stylus (Alamargot & Morin, 2015; Gerth et al., 2016). These studies showed that when acting with a stylus, the low-friction surface of a tablet induces a modification of proprioceptive feedbacks to control movement. Authors reported that this sliding effect disturbs handwriting on a smooth surface such that the legibility of letters is diminished. Children and adolescents (Alamargot & Morin, 2015; Guilbert, Alamargot, & Morin, 2019) compensate the loss of proprioceptive information needed to control writing movement by amplifying their movement (they produce bigger letters) and increasing pen velocity. More precisely, Alamargot and Morin (2015) showed that writing with a stylus on tablet differently affected movement execution according to the age of participants: children aged 7/8 years increased their pauses (and thus increasing duration of movement) whereas by 10/11 years, children increased pen pressure and pen speed. Gerth et al. (2016) also reported that experimented users including adults compensate the lower friction between stylus and tablet surface by increasing pressure and letter size. These kinematic changes observed before and after 8 years old are linked to a switch in the motor control of action with age, with children using a backward motor control for movements up to 8 years old and then using a feedforward motor control of action. After 8 years old, the sliding effect of the tablet would be compensated by the use of feedforward motor control of action (Guilbert et al., 2019). Thus, during handwriting tasks which call on automatization of motor programs, more experienced users compensated the loss in proprioceptive feedback by using feedforward strategies, that is by relying more on the prediction of the ongoing action (Guilbert et al., 2019; Kandel & Perret, 2015).

In the context of a drawing task, it could be suggested that the ability of children older than 11 years to rely on feedforward strategies when acting on the tablet to compensate for the loss of proprioceptive information could foster creativity during the drawing task, by enhancing the variation-to-selection process of the generation of creative ideas, operating on the same model

than for off-line simulation of actions (Dietrich & Haider, 2015; Valtulina & de Rooij, 2019). This hypothesis would be consistent with our results showing benefits in originality of the drawing when using stylus on tablet instead of a pen on paper. We suggest that, in an original drawing task, the sliding effect required a compensation by simulation of actions, which supported creativity since both simulation and creativity processes borrow the same path. The simulation process being over-mobilized when the user is disturbed by the smooth surface also allows to boost creativity process in a drawing task.

4.3. Finger and stylus

Results from the present study showed no significant difference between drawings made with finger and drawings made with stylus on tablet. However, although this result remains tendential and needs to be confirmed with a larger sample of participants, it highlights our interpretation of a compensating effect of simulation process when using a stylus. Drawing with finger would lead to better performances in originality than with pen on paper because this situation would foster feedforward motor control thanks to an enrichment of proprioceptive feedback. Drawing with a stylus would also lead to better performances in originality than with pen on paper because this situation would make adolescents rely more on feedforward strategies to compensate for the loss of proprioceptive feedbacks due to the sliding effect of the stylus on the smooth surface. The smooth surface of tablets would then allow a major use of feedforward strategies in the control of actions, borrowing the same mechanisms than the ones leading to creativity process (Dietrich & Haider, 2015). Tablet's positive effect on originality in a drawing task with finger and stylus would then be explained by the increased use of simulation that would facilitate the process of creativity by generating a wide range of motor actions to be executed. Creativity, mobilizing simulation process, is thus fostered when the prediction

mechanism is urged by an increase of kinesthetic information (finger situation) and when this prediction mechanism is essential to compensate for a kinesthetic loss (stylus situation).

Future research should track and compare kinematics of movement in the three different drawing conditions proposed in the present research to explore further the prediction mechanism that should, as suggested by our hypothesis, be enhanced when acting on a tablet with finger but also with a stylus, compared to drawings executed on paper with pen.

4.4. Limitations

Main limitation of the study could be seen in the procedure used to control for order effect. It could be suggested that the difference observed between drawings made on tablet (either with fingers or with stylus) and drawings made on paper could be related to the order of execution of each drawing. Because drawing on paper was performed after drawing on tablet, adolescents could have got tired or less inspired for the production of something completely different from what they produced during the first two trials on tablet. To avoid this possibility, adolescents were asked to produce the two versions of a house (original and unoriginal) on paper two months after their drawings on tablet. Against the argument of an order effect of execution of drawings on paper or on tablet, no order effect on originality score was observed for drawing on tablet. Order of presentation of drawings made on tablet with finger or stylus did not affect the original score: whatever adolescents drew first with stylus or with finger, original scores were not significantly different between the two conditions. Since no order effect was observed for two successive drawings executed in a same session, it could hardly be expected that an order effect would have affected the production of drawings executed with an interval of two months. One constraint of the present study comes from the use of a non-standardized scale inspired from studies with children, to assess general creativity in drawings produced by adolescents. Indeed, our scale was based on a few studies tracking house drawing and

originality of children rather than of adolescents (Barrouillet et al., 1994; Picard et al., 2014; Karmiloff-Smith, 1990). Although graphical procedures have been widely studied in pre-school and school children since the first description of Luquet (1927), graphical procedures used by teenagers should be better known in order to better appreciate their variation in the context of original drawing. Future research should emphasize this point independently from any creative context.

5. Conclusion

To conclude, this study contributes to a better understanding of tablet use on drawing creativity. This work was based on the theoretical propositions of Dietrich and Haider (2015) according to which creativity is rooted in the process of motor simulation such as direct models would be used for generating new ideas and inverse models for evaluating and selecting the variation of ideas.

We hypothesized that tablets would foster originality thanks to off-line simulation this device would promote. In line with this idea, we observed that when adolescents were placed in situations that either reduced (when using a stylus) or enhanced (when drawing with finger) proprioceptive information, originality scores were higher than when drawing with a pen on paper. Using fingertip on the interface gives rise to an enhancement of the direct feedback that is extended to off-line simulation thanks to internal loop (Wolpert & Kawato, 1998). When using the stylus, off-line simulations are solicited to compensate for a loss in proprioceptive information in the direct feedback (Alamargot & Morin, 2015; Guilbert et al., 2019). This compensation in the use of stylus brings positive effect in the case of original drawing, whereas it diminishes letter legibility in a writing task. The facilitator effect of tablet use with stylus appears thus to be dependent from the task since, in opposite to our positive results in a drawing task, negative effects were found in a writing task (Alamargot & Morin, 2015).

The question remains to know whether using tablets can also help children and adolescents with motor disabilities. For instance, children and adolescents with developmental coordination disorders (DCD) are known to present some difficulty in feedforward motor control as revealed by motor imagery tasks (Wilson et al., 2004). By promoting simulation process involved in the off-line control of motor action, digital tablets could thus offer a valuable environment for helping DCD children and adolescents to improve motor control abilities. Further research should investigate this perspective.

Post-print

REFERENCES

- Alamargot, D., & Morin, M. F. (2015). Does handwriting on a tablet screen affect students' graphomotor execution? A comparison between grades two and nine. *Human movement science, 44*, 32-41. <https://doi.org/10.1016/j.humov.2015.08.011>
- Barrouillet, P., Fayol, M., & Chevrot, C. (1994). Le dessin d'une maison. Construction d'une échelle de développement. *L'Année Psychologique, 94*, 81-98.
- Black, J. B. (2010). An embodied/grounded cognition perspective on educational technology. In *New science of learning* (pp. 45-52). Springer, New York, NY. https://doi.org/10.1007/978-1-4419-5716-0_3
- Choudhury, S., Charman, T., Bird, V., & Blakemore, S. J. (2007). Development of action representation during adolescence. *Neuropsychologia, 45*(2), 255-262. <https://doi.org/10.1016/j.neuropsychologia.2006.07.010>
- Chiappedi, M., Togni, R., De Bernardi, E., Baschenis, I. M. C., Battezzato, S., Balottin, U., ... & Bejor, M. (2012). Arm trajectories and writing strategy in healthy children. *BMC pediatrics, 12*(1), 1-6. <https://doi.org/10.1186/1471-2431-12-173>
- Clark, A. (1998). *Being there: Putting brain, body, and world together again*. MIT press.
- Clark, A. (2008). *Supersizing the mind: Embodiment, action, and cognitive extension*. USA: Oxford University Press.
- Cooper, L. Z. (2005). Developmentally appropriate digital environments for young children. *Library trends, 54*(2), 286-302. <https://doi.org/10.1353/lib.2006.0014>.
- Dietrich, A., & Haider, H. (2015). Human creativity, evolutionary algorithms, and predictive representations: The mechanics of thought trials. *Psychonomic bulletin & review, 22*(4), 897-915. <https://doi.org/10.3758/s13423-014-0743-x>
- Dubé, A. K., & McEwen, R. N. (2015). Do gestures matter? The implications of using touchscreen devices in mathematics instruction. *Learning and Instruction, 40*, 89-98. <https://doi.org/10.1016/j.learninstruc.2015.09.002>
- Duff, W. (1767). *An Essay on Original Genius, and Its Various Modes of Exertien in Philosophy and the Fine Arts, Particulary*. Edward & Charles Dilly.
- Fodor, J. A. (1985). Precis of the modularity of mind. *Behavioral and brain sciences, 8*(1), 1-5. <https://doi.org/10.1017/S0140525X0001921X>
- Fogassi, L., & Gallese, V. (2004). Action as a binding key to multisensory integration. *The handbook of multisensory processes, 425-441*.
- Foglia, L., & Wilson, R. A. (2013). Embodied cognition. *Wiley Interdisciplinary Reviews: Cognitive Science, 4*(3), 319-325. <https://doi.org/10.1002/wcs.1226>
- Geist, E. A. (2012). A qualitative examination of two year-olds interaction with tablet based interactive technology. *Journal of Instructional Psychology, 39*(1).
- Gerth, S., Klassert, A., Dolk, T., Fliesser, M., Fischer, M. H., Nottbusch, G., & Festman, J. (2016). Is handwriting performance affected by the writing surface? Comparing preschoolers', second graders', and adults' writing performance on a tablet vs. Paper. *Frontiers in psychology, 7*, 1308.

- Glenberg, A. M. (2010). Embodiment as a unifying perspective for psychology. *Wiley Interdisciplinary Reviews: Cognitive Science*, 1(4), 586-596. <https://doi.org/10.1002/wcs.55>
- Grush, R. (2004). The emulation theory of representation: Motor control, imagery, and perception. *Behavioral and brain sciences*, 27(3), 377.
- Guilbert, J., Alamargot, D., & Morin, M. F. (2019). Handwriting on a tablet screen: Role of visual and proprioceptive feedback in the control of movement by children and adults. *Human movement science*, 65, 30-41.
- Guilbert, J., Jouen, F., Lehalle, H., & Molina, M. (2013). Imagerie motrice interne et simulation de l'action chez l'enfant. *L'Annee psychologique*, 113(3), 459-488.
- Guilbert, J., Molina, M., & Jouen, F. (2016). Rôle des afférences proprioceptives dans le développement de l'imagerie motrice chez l'enfant. *Canadian Journal of Experimental Psychology/Revue canadienne de psychologie expérimentale*, 70(4), 343.
- Hay, L. (1978). Accuracy of children on an open-loop pointing task. *Perceptual and Motor Skills*, 47(3_suppl), 1079-1082. <https://doi.org/10.2466/pms.1978.47.3f.1079>
- Ishii, H. (2008). The tangible user interface and its evolution. *Communications of the ACM*, 51(6), 32. <https://doi.org/10.1145/1349026.1349034>
- James, W. (1880). *The feeling of effort*. The Society.
- Jeannerod, M. (1994). The representing brain: Neural correlates of motor intention and imagery. *Behavioral and Brain sciences*, 17(2), 187-201.
- Kandel, S., & Perret, C. (2015). How do movements to produce letters become automatic during writing acquisition? Investigating the development of motor anticipation. *International Journal of Behavioral Development*, 39(2), 113-120.
- Karmiloff-Smith, A. (1990). Constraints on representational change: Evidence from children's drawing. *Cognition*, 34(1), 57-83. [https://doi.org/10.1016/0010-0277\(90\)90031-E](https://doi.org/10.1016/0010-0277(90)90031-E)
- Kawato, M. (1999). Internal models for motor control and trajectory planning. *Current opinion in neurobiology*, 9(6), 718-727.
- Koziol, L. F., Budding, D. E., & Chidekel, D. (2012). From movement to thought: executive function, embodied cognition, and the cerebellum. *The Cerebellum*, 11(2), 505-525.
- Lederman, S. J., & Klatzky, R. L. (1987). Hand movements: A window into haptic object recognition. *Cognitive psychology*, 19(3), 342-368. [https://doi.org/10.1016/0010-0285\(87\)90008-9](https://doi.org/10.1016/0010-0285(87)90008-9)
- Lubart, T., Besançon, M., & Barbot, B. (2011). *EPOC: évaluation du potentiel créatif*. Paris: Hogrefe.
- Lubart, T. I., & Georgsdottir, A. S. (2004). Créativité, haut potentiel et talent. *Psychologie française*, 49(3), 277-291.
- Lubart, T., Mouchiroud, C., Tordjam, S., & Zenasni, F. (2003). *Psychologie de la créativité*. Paris: Armand Colin.
- Luquet, G. H. (1927). *Le dessin enfantin. (Bibliothèque de psychologie de l'enfant et de pédagogie.)* [Children's drawing].

- McManis, L. D., & Gunnewig, S. B. (2012). Finding the education in educational technology with early learners. *Young Children*, 67(3), 14-24.
- Miall, R. C., & Wolpert, D. M. (1996). Forward models for physiological motor control. *Neural networks*, 9(8), 1265-1279.
- Mouchiroud, C., & Lubart, T. I. (2001). Children's original thinking : An empirical examination of alternative measures derived from divergent thinking tasks. *Journal of Genetic Psychology*, 162(4), 382-401. <https://doi.org/10.1080/00221320109597491>
- Patchan, M. M., & Puranik, C. S. (2016). Using tablet computers to teach preschool children to write letters: Exploring the impact of extrinsic and intrinsic feedback. *Computers & Education*, 102, 128-137. <https://doi.org/10.1016/j.compedu.2016.07.007>
- Pezzulo, G. (2011). Grounding procedural and declarative knowledge in sensorimotor anticipation. *Mind & Language*, 26(1), 78-114. <https://doi.org/10.1111/j.1468-0017.2010.01411.x>
- Picard, D., & Boulhais, M. (2011). Sex differences in expressive drawing. *Personality and Individual Differences*, 51(7), 850-855.
- Picard, D., & Gauthier, C. (2012). The development of expressive drawing abilities during childhood and into adolescence. *Child Development Research*, 2012.
- Picard, D., Martin, P., & Tsao, R. (2014). iPads at school? A quantitative comparison of elementary schoolchildren's pen-on-paper versus finger-on-screen drawing skills. *Journal of Educational Computing Research*, 50(2), 203-212. <https://doi.org/10.2190/EC.50.2.c>
- Piotrowski, J. T., & Meester, L. (2018). Can apps support creativity in middle childhood? *Computers in Human Behavior*, 85, 23-33. <https://doi.org/10.1016/j.chb.2018.03.030>
- Rideout, V. (2016). Measuring time spent with media: The Common Sense census of media use by US 8-to 18-year-olds. *Journal of Children and Media*, 10(1), 138-144.
- Rideout, V. (2017). The Common Sense census: Media use by kids age zero to eight. *San Francisco, CA: Common Sense Media*, 263-283.
- Roskos, K., Burstein, K., Shang, Y., & Gray, E. (2014). Young Children's Engagement With E-Books at School: Does Device Matter? *SAGE Open*. <https://doi.org/10.1177/2158244013517244>
- Runco, M. A. (1991). The evaluative, valuative, and divergent thinking of children. *The Journal of Creative Behavior*.
- Sakr, M. (2018). Multimodal participation frameworks during young children's collaborative drawing on paper and on the iPad. *Thinking Skills and Creativity*, 29, 1-11. <https://doi.org/10.1016/j.tsc.2018.05.004>
- Smits-Engelsman, B. C., & Wilson, P. H. (2013). Age-related changes in motor imagery from early childhood to adulthood: probing the internal representation of speed-accuracy trade-offs. *Human Movement Science*, 32(5), 1151-1162. <https://doi.org/10.1016/j.humov.2012.06.006>

- Spackman, J. S., & Yanchar, S. C. (2014). Embodied cognition, representationalism, and mechanism: a review and analysis. *Journal for the Theory of Social Behaviour*, 44(1), 46-79. <https://doi.org/10.1111/jtsb.12028>
- Spearman, C. D. (1931). Creative mind. *The Journal of Nervous and Mental Disease*, 74(6), 783.
- Valtulina, J., & de Rooij, A. (2019). The predictive creative mind: A first look at spontaneous predictions and evaluations during idea generation. *Frontiers in psychology*, 10, 2465. <https://doi.org/10.3389/fpsyg.2019.02465>
- Wolpert, D. M., & Ghahramani, Z. (2004). Computational motor control. *Science*, 269, 1880-1882.
- Wolpert, D. M., Ghahramani, Z., & Jordan, M. I. (1995). An internal model for sensorimotor integration. *Science*, 269(5232), 1880-1882.
- Wolpert, D. M., & Kawato, M. (1998). Multiple paired forward and inverse models for motor control. *Neural networks*, 11(7-8), 1317-1329.
- Willems, R. M., & Francken, J. C. (2012). Embodied cognition: taking the next step. *Frontiers in Psychology*, 3, 582. <https://doi.org/10.3389/fpsyg.2012.00582>
- Wilson, M. (2002). Six views of embodied cognition. *Psychonomic bulletin & review*, 9(4), 625-636. <https://doi.org/10.3758/BF03196322>
- Wilson, P. H., Maruff, P., Butson, M., Williams, J., Lum, J., & Thomas, P. R. (2004). Internal representation of movement in children with developmental coordination disorder: a mental rotation task. *Developmental Medicine & Child Neurology*, 46(11), 754-759.