Thesis

Analogical reasoning and working memory in students with intellectual disability : effects of actively constructing the response on a touch screen

DENAES, Caroline

Abstract

This thesis project focused on the evaluation of a memory overload hypothesis in analogical reasoning tasks. It is said that individuals with moderate intellectual disability (mental age: 4-7) are confronted to a memory overload when they have to treat several relations at the same time in analogical matrices. In order to test this assumption, we created a computerized test using a touch screen, the Revised - Construction of Analogical Matrices Test (CAM-R), composed of a construction version, supposed to unload the memory, and a control version, supposed to overload the memory. As expected, memory abilities played a crucial role in the classic version and less in the construction version. Our results strongly indicated that, with the support of external memories, participants with moderate intellectual disability obtained better performances than without such support, and were able to reach a similar level of performance as typically developing children of the same mental age.

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Sous la direction de Fredi Büchel et Mireille Bétrancourt

Analogical reasoning and working memory in students with intellectual disability:

Effects of actively constructing the response on a touch screen.

THESE

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Caroline DENAES-BRUTTIN

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Effects of actively constructing the response on a Touch Screen

THESIS

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Caroline DENAES-BRUTTIN

Jury members:

Professor Fredi Büchel, co-director, University of Geneva

Professor Mireille Bétrancourt, co-director, University of Geneva

Professor Sylvie Cèbe, University of Geneva

Professor Wilma Resing, University of Leiden, The Netherlands

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Abbreviations list (in order of appearance)

ARLT: Analogical Reasoning Learning Test

CAM: Construction of Analogical Matrices Test

CAM-R: Revised Construction of Analogical Matrices Test

AR: Analogical reasoning

ID: Intellectual disability

AAMR: American Association on Mental Retardation

AAIDD: American Association on Intellectual and Developmental Disabilities

CCPAM: Children's Conceptual and Perceptual Analogical Modifiability Test

WM: working memory

STM: short-term memory

LTM: long-term memory

LT-WM: long-term working memory

ST-WM: short-term working memory

CA: chronological age

MA: mental age

TARC: Test of Analogical Reasoning in Children

TD: typically developing

ANOVA: analysis of variance

MANOVA: multivariate analysis of variance

"One must keep in mind that any child with a disability is first of all a child and only afterwards an impaired child... One must not perceive in the child with a disability only the defect, the "grams" of the illness and not notice the "kilograms" of health which children possess. From the psychological and pedagogical points of view, one must treat the child with a disability in the same way as a normal one"

(Vygotsky, 1995, quoted by Vygotskaya, 1999, p.331)

RESUME EN FRANCAIS (French summary)

A. INTRODUCTION

Le centre d'intérêt primordial de cette thèse consiste en l'évaluation d'une hypothèse de surcharge mnésique qui concerne les personnes présentant une déficience intellectuelle, surcharge qui les empêche d'obtenir de bonnes performances dans les tâches de raisonnement analogique. Afin de tester cette hypothèse, nous avons créé un test informatisé de raisonnement analogique composé d'une version de construction, supposée décharger la mémoire et d'une version contrôle, supposée la surcharger.

De nos jours, nous pouvons trouver des analogies dans de nombreux contextes divers et variés. Par exemple, certains chercheurs ont démontré que le raisonnement analogique était fondamental dans tout processus de lecture (Goswami & Brown, 1990; Snowling, 1994), ainsi que pour la construction d'hypothèses (Tzuriel & Flor-Maduel, 2010). De plus, le raisonnement analogique est une composante centrale de l'intelligence humaine (Holyoak, Junn, & Billman, 1984) et fait partie de la pensée inductive, elle-même considérée comme un important mécanisme dans l'apprentissage et la résolution de problèmes (Gentner, 2003 ; Gentner, Holyoak, & Kokinov, 2001; Goswami, 1992 ; Holyoak, 2005).

Les analogies classiques, la plupart du temps présentées sous forme linéaire (*A:B::C:D*) ou en matrices, représentent généralement le moyen utilisé pour mesurer le raisonnement analogique dans les tests de QI. D'ordinaire, il s'agit de trouver le quatrième élément (*D*) d'un groupe, en découvrant la relation existante entre les deux premiers éléments de la tâche (*A* et *B*) et en l'appliquant à un troisième (*C*). Par exemple, l'analogie *Arbre : Forêt :: Chambre :* (a. *Porte*, b. *Fenêtre*, c. *Maison*, d. *Cuisine*), nécessite la coordination de plusieurs processus, d'ailleurs décrits entre autres par Sternberg (1977a), tels que l'encodage des termes *A*, *B*, et *C* (*Arbre, Forêt, Chambre*), l'induction de la relation entre les termes *A* et *B* (ici, une relation partie-tout), l'application de la relation du terme *C* à chaque possibilité de réponse (ici, la *Chambre* est une partie de la *Maison*), et enfin la réponse (Robins & Mayer, 1993). En d'autres termes, afin de trouver la réponse D, il s'agit d'appliquer la règle « A est à B ce que C est à D » (Pellegrino, 1985).

Les tests de QI statiques traditionnels mesurent le fonctionnement cognitif des individus avec et sans déficience intellectuelle. Ces tests comportent de nombreuses instructions et aucun feedback. De nombreux chercheurs reconnaissent que ces tests ne reflètent pas le potentiel cognitif des individus. Malgré cela, ils demeurent les tests les plus utilisés (Sternberg, 1985). D'un autre côté, des procédures dynamiques ont prouvé leur efficacité, spécialement avec les personnes ayant une déficience intellectuelle (Budoff, 1987). Néanmoins, ces procédures ont également été critiquées pour leur manque de standardisation.

En prenant en compte les critiques faites à l'encontre des tests de QI statiques et des procédures dynamiques, deux études ont conçu deux tests analogiques pour les personnes ayant une déficience intellectuelle. La première étude (Büchel, Schlatter, & Scharnhorst,

1997) a porté sur l'élaboration d'un test analogique présenté sur des matrices en bois, le Test d'Apprentissage de la Pensée Analogique (TAPA). Les participants étaient confrontés aux parties *A*, *B* et *C* de la matrice et devaient choisir la réponse *D* parmi six ou huit possibilités. La seconde étude (Angeretas & Gonzalez, 2002) a porté sur la création d'un test analogique informatisé avec écran tactile, les Matrices Analogiques de Construction (MAC). La distinction principale de ce second test consistait dans le fait que les participants devaient résoudre les analogies en construisant la bonne réponse pas à pas et non plus en choisissant la bonne réponse parmi plusieurs alternatives comme dans la première étude. Les éléments de réponse étaient constamment présents au bas de la matrice et représentaient des mémoires externes. En effet, une fois que le participant avait découvert une relation et sélectionné un élément avec son doigt, il pouvait considérer une deuxième relation sans devoir mémoriser celles qu'il avait déjà traitées auparavant.

Les résultats de ces deux études ont démontré que, parmi les trente-six participants testés, deux tiers n'ont pas pu résoudre des analogies composées de trois relations dans le TAPA, alors qu'ils ont été capables d'en résoudre des plus complexes dans le MAC. Afin d'expliquer ces résultats, Büchel (2006) a émis l'hypothèse d'une surcharge mnésique. Selon cet auteur, les participants ne présentaient pas, à première vue, de déficit en raisonnement analogique, mais plutôt en mémoire de travail, ce qui les empêchait de mémoriser plusieurs relations en même temps. Les mémoires externes présentes dans le MAC ont pu permettre aux participants de décharger leur mémoire et de résoudre des analogies d'un niveau de complexité plus élevé que dans le TAPA.

Cependant, les deux études ont présenté quelques limites, parmi lesquelles le fait que les deux tests n'étaient pas présentés sur le même support (matrices en bois vs. écran tactile). Notre étude est une continuation des deux études précédentes consistant en une élaboration complémentaire et actualisée. Nous avons conçu un nouveau test analogique, les Matrices Analogiques de Construction-Révisées (MAC-R) composé d'une version de construction, qui propose de construire la réponse pas à pas (même format que dans le MAC) à l'aide d'éléments qui constituent des mémoires externes. Cette version de construction sera opposée à une version de contrôle, appelée version classique, qui propose de choisir la bonne réponse parmi plusieurs alternatives (même format que dans le TAPA). La comparaison des deux versions pourra ainsi se faire sur le même support, ce qui résoudra la critique énoncée ci-dessus.

L'objectif principal de cette recherche est de tester si une réduction de la surcharge mnésique dans une tâche de raisonnement analogique peut améliorer ou non les performances des individus ayant une déficience intellectuelle et des jeunes enfants de même âge mental. Nous supposons que les mémoires externes présentes dans la version de construction offrent des conditions favorables pour l'obtention de bonnes performances en matière de raisonnement analogique puisqu'elles sont supposées décharger la mémoire. Deuxièmement, le matériel attrayant que nous avons conçu, c'est-à-dire un ordinateur avec un écran tactile présentant des analogies composées de relations et d'éléments familiers, propose également de bonnes occasions pour de bons résultats puisqu'il est supposé motiver les participants dans leur résolution.

Dans ce résumé, nous ne pouvons pas traiter l'entier des parties théorique et empirique de cette thèse. Nous allons donc uniquement considérer la quintessence du travail présenté dans le document original en anglais.

B. RAISONNEMENT ANALOGIQUE

B.1 Définition du raisonnement analogique

Le terme « analogie » nous vient de l'Antiquité: Aristote l'a défini comme une égalité de proportions impliquant au moins quatre termes, tels que le deuxième est lié au premier comme le quatrième l'est au troisième (Aristotle, *Metaphysics*, cité dans Pellegrino, 1985).

Plusieurs chercheurs ont expliqué à quoi servaient les analogies. Gentner a affirmé que le processus de raisonnement analogique rendait le transfert réel (Gentner, Loewenstein & Thompson, 2003); Holyoak (1984; Holyoak & Thagard, 1997) a accentué le fait que le transfert était fondé sur une structure analogique ; et Crisafi & Brown (1986) ont prouvé que le raisonnement analogique était utile pour résoudre des problèmes.

B.2 Mesure du raisonnement analogique

L'habileté en raisonnement analogique est généralement mesurée par deux tâches différentes : les analogies classiques et les problèmes. Le format traditionnel est représenté par les analogiques classiques, dont nous avons déjà présenté un exemple dans l'introduction. Quant aux problèmes, ils requièrent du participant de transférer une connaissance obtenue d'après un problème déjà résolu (la base) à un nouveau problème (la cible) en découvrant la relation de similitude entre la base et la cible (Gentner & Forbus, 2010).

Dans les deux tâches, le but est de comparer les éléments (ou situations) en termes de similitudes et de différences, d'inférer les relations entre les éléments (ou situations) et d'appliquer ces relations, afin de découvrir la solution (Klauer, 1990). Quelque soit le format, l'habileté en raisonnement analogique ne se développe pas de la même manière chez les jeunes enfants ou chez les plus âgés, de même que chez les personnes ordinaires ou celles ayant une déficience intellectuelle. Plusieurs raisons expliquent cette différence d'habileté, notamment une immaturité des structures cognitives (Goswami, 1989 ; Halford, Wilson, & Phillips, 1998), des limites en mémoire de travail (Halford, 1992, 1993), ou encore le développement graduel de certaines régions cérébrales (Gogtay *et al.*, 2004; O'Donnell, Noseworthy, Levine, & Dennis, 2005).

B.3 Raisonnement analogique chez les enfants

Un des auteurs les plus connus à avoir théorisé le développement du raisonnement analogique est Piaget, selon qui cette habileté est tardive et n'apparaît que vers les onze-douze ans, dans la période opérationnelle formelle (Piaget, Montangero, & Billeter, 1977). De nombreuses études ont corroboré ce point de vue, alors que d'autres ont démontré l'inverse : de très jeunes enfants, dès l'âge de quatre ans, sont capables de résoudre des analogies, tant que les relations impliquées leur sont familières (par ex. Alexander, Willson, White, & Fuqua, 1987; Goswami, 1992 ; Goswami & Brown, 1989, 1990).

Cette affirmation a été contestée à son tour par certains auteurs (p. ex., Gallagher & Wright, 1979; Sternberg & Downing, 1982), argumentant que les jeunes enfants raisonnent non pas par analogie, mais par association, celle-ci étant une forme de raisonnement ne requérant pas la pleine compréhension des relations. Afin de prouver la capacité des enfants à raisonner par analogie, Goswami et Brown (1989, 1990) ont créé deux tests, présentés à des enfants de 4, 5 et 9 ans, composés exclusivement d'analogies linéaires, de type *morceau de pain:tranche de pain = citron:?*. Les éléments de réponse étaient composés d'une seule réponse analogique (ici *tranche de citron*) et de quatre réponses associatives (ici *tranche de cake, moitiés de citron pressées, ballon jaune* et *citron*), chacune d'entre elles ayant une relation en commun avec l'analogie (couleur, forme, etc.). Avec ce matériel, les auteurs voulaient vérifier si les enfants raisonnaient effectivement par analogie ou s'ils étaient attirés, au contraire, par les associations. Les résultats ont montré que les enfants de 4, 5 et 9 ans ont été capables de raisonner par analogie avec des pourcentages élevés (respectivement, 60%, 65% et 100%), du fait que les relations utilisées leur étaient familières.

Dans notre test, le MAC-R, nous avons également placé des associations parmi les éléments de réponse, afin de tester si nos participants raisonnaient effectivement par analogie, du fait des relations familières, ou s'ils raisonnaient plutôt par association.

B.4 Difficulté des analogies

La familiarité des relations n'est pas la seule composante de la difficulté des analogies. Une autre est représentée par le nombre de relations impliquées entre les éléments *A*, *B* et *C* (Mulholland, Pellegrino, & Glaser, 1980), qui augmentent généralement selon les différents niveaux de complexité du test. Afin de découvrir la solution, le participant doit maintenir en mémoire toutes les relations. Ainsi, plus le nombre d'informations à retenir augmente, plus la charge mnésique est importante, ce qui peut provoquer la perte d'une partie des informations (Sternberg, 1977a).

Une autre difficulté repose dans la distinction entre les analogies perceptuelles et conceptuelles. Cette distinction est particulièrement importante pour cette thèse, puisque nous avons également distingué ces deux types d'analogies dans notre propre test (MAC-R). Selon Piaget et ses collaborateurs (Piaget *et al.*, 1977), ainsi que Klein et Stafford (1978), les analogies perceptuelles sont plus complexes à résoudre que les analogies conceptuelles, car les premières sont fondées sur des relations visuelles-perceptives, qui nécessitent la considération d'au moins deux caractéristiques (par ex., la couleur et la forme), alors que les secondes reposent sur des relations sémantiques abstraites, qui requièrent seulement la considération d'une seule caractéristique. Comme Piaget l'a démontré, la considération d'une seule caractéristique fait référence au stade pré-opérationnel, alors que la considération de deux caractéristiques se réfère au stade opérationnel concret.

Cependant, d'autres auteurs ont démontré l'inverse, c'est-à-dire que les relations perceptuelles étaient plus faciles à résoudre que les relations conceptuelles (p.ex., Carpenter, Just, & Shell, 1990 ; Gentner, 2003 ; Gentner & Ratterman, 1991 ; Tzuriel & Galinka, 2000). Selon Tzuriel (2007 ; Tzuriel & Galinka, 2000), les analogies perceptuelles comprennent des relations visibles immédiatement, alors que les analogies conceptuelles nécessitent une abstraction de relations, ce qui représente un processus plus complexe.

Après nous être intéressés au développement du raisonnement analogique chez les jeunes enfants, nous nous concentrons désormais sur le même sujet chez des personnes ayant une déficience intellectuelle, puisque les deux populations font partie intégrante de notre population de recherche. En effet, les performances d'adolescents ayant une déficience intellectuelle vont être comparées à celles d'enfants du même âge mental, lors de la passation du MAC-R que nous décrirons plus tard. Avant de décrire les capacités des personnes déficientes intellectuellement en matière de raisonnement analogique, nous allons d'abord définir quelques notions théoriques.

C. INTELLIGENCE ET SES DIFFERENCES INDIVIDUELLES

C.1 Définition de l'intelligence

L'intelligence est une habileté mentale générale qui inclut, notamment, la capacité de raisonner, planifier, résoudre des problèmes, penser de manière abstraite, comprendre des idées complexes et apprendre par expérience (Luckasson *et al*., 2010). L'intelligence est généralement évaluée par une mesure du QI, distribuée sur une courbe de Gauss, avec une moyenne de 100 et un écart type de 15 (Grossman, 1973). Lorsqu'un diagnostic de déficience intellectuelle est attribué à des individus, cela signifie une déviation par rapport à un fonctionnement « dans la norme ». Environ 70% de la population se situe à plus ou moins un écart-type de la moyenne (QI 85 $\leq M \leq$ QI 115). Un score d'environ 70 indique une limitation dans le fonctionnement intellectuel (AAIDD, 2011).

Selon la onzième édition de l'*American Association on Intellectual and Developmental Disabilities* (AAIDD, 2011), la définition actuelle de la déficience intellectuelle est caractérisée par des limitations significatives dans le fonctionnement intellectuel et dans le comportement adaptatif, comprenant des habiletés conceptuelles, sociales et pratiques. L'origine de la déficience doit survenir avant l'âge de 18 ans.

C.2 Origine de la déficience intellectuelle : la controverse entre la théorie développementale et la théorie déficitaire

Il est reconnu que les enfants ayant une déficience intellectuelle obtiennent des performances moindres en comparaison des enfants sans déficience sur de nombreuses tâches. Deux théories majeures ont tenté d'expliquer l'origine de la déficience intellectuelle.

Brièvement décrite, la théorie développementale affirme que les enfants déficients passent par les mêmes étapes de développement que les enfants ordinaires, mais leur développement cognitif est plus lent et ils atteignent un niveau final plus bas (Ellis & Cavalier, 1982 ; Meador & Ellis, 1987). Ainsi, des enfants déficients et ordinaires appariés sur le même âge mental, mais avec un âge chronologique différent, devraient présenter des processus cognitifs et des performances similaires (Baumeister, 1994; Bennett-Gates & Zigler, 1998; Hodapp & Zigler, 1997; Weisz, Yeates, & Zigler, 1982; Zigler & Balla, 1982a).

La théorie déficitaire, quant à elle, affirme que de nombreux déficits sont responsables de la déficience des individus, comme une mémoire déficiente (Ellis, 1978), de faibles processus d'organisation (Spitz, 1966), un déficit d'attention (Zeaman & House, 1984), ou encore une inefficacité à utiliser des stratégies (e.g., Bray, Huffman, & Grupe, 1998; Bray, Saarnio, Borges, & Hawk, 1994; Brown, Bransford, Ferrara, & Campione, 1983).

Plusieurs chercheurs ont tenté de résoudre cette controverse. Paour (2004), par exemple, a proposé une conception intégrative de la déficience intellectuelle. Selon cet auteur, la déficience intellectuelle est le résultat d'interactions entre trois composantes majeures. La première est une limitation des capacités basiques en traitement de l'information : les individus déficients présentent des déficits dans la vitesse, la qualité et la quantité d'informations traitées. La deuxième est un sous-fonctionnement cognitif chronique : les personnes déficientes sont moins capables de mobiliser leur potentiel cognitif de manière efficace. Enfin, la troisième représente les conséquences développementales des deux premières composantes, comme un retard, une lenteur, un inachèvement ou un arrêt de la tâche.

C.3 Habiletés de raisonnement chez les personnes ayant une déficience intellectuelle

Comme précédemment évoqué, les personnes déficientes présentent des fonctions cognitives déficientes, en comparaison des personnes à développement typique, dans différents domaines comme la mémoire (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Numminen, Service, & Ruoppila, 2002), ou encore le raisonnement inductif (Lifshitz, Tzuriel, & Weiss, 2005). De plus, ces personnes ressentent, en général, moins de motivation que les personnes ordinaires (Tassé, Morin, & Aunos, 2003) et sont plus vite confrontées à des expériences négatives, dont l'échec (Agran & Wehmeyer, 2005; Switzky, 1997). Par ailleurs, les personnes déficientes tendent à prendre plus de temps que les personnes ordinaires pour résoudre des tâches et à commettre plus d'erreurs également (Foorman, Sadowski, & Basen, 1985 ; Sternberg & Rifkin, 1979).

Pour les personnes ayant une déficience intellectuelle modérée (QI : 35-40 à 50-55 ; âge mental : 4-7 ans), qui constituent, en partie, notre population de recherche, les analogies représentent une tâche difficile : en général, elles n'explorent pas toutes les informations à disposition (Paour, 1992) ; elles ont tendance à ne pas comparer suffisamment les informations entre elles, ce qui est nécessaire pour résoudre les analogies ; elles démontrent une faiblesse, voire une incapacité, à atteindre un certain niveau d'abstraction (Primi, 2001) ; elles utilisent rarement l'autorépétition, processus permettant de maintenir les informations plus longtemps en mémoire (Dulaney & Ellis, 1991). De plus, leur empan mnésique est limité, pouvant généralement maintenir deux ou trois éléments simultanément (Hulme & Mackenzie, 1992), alors que les personnes adultes ordinaires ont un empan de 7 ± 2 (Miller, 1956 ; voir chapitre Mémoire).

D. MESURE DU RAISONNEMENT ANALOGIQUE CHEZ LES PERSONNES PRESENTANT UNE DEFICIENCE INTELLECTUELLE

D.1 Tests de QI versus Tests d'apprentissage

Les tests de QI possèdent des qualités psychométriques évidentes, dont la valeur est reconnue depuis de nombreuses années. Cependant, ces tests mesurent le niveau actuel de performances d'un individu à un moment donné et non tout ce qui a été appris auparavant. De plus, ils ne donnent pas d'informations sur la capacité d'apprentissage de ces personnes, ni sur une quelconque action corrective qui pourrait les aider à obtenir de meilleures performances (Resing, 1993; Chen & Siegler, 2000). Les tests de QI tendent à ignorer l'influence de facteurs tels que la motivation, l'anxiété, ou encore la confiance en soi, facteurs qui ont une importance capitale pour réussir une tâche (Haywood & Switzky, 1986; Tzuriel, 2001). Les tests de QI ne conviennent pas pour les populations dites spéciales, comme celles ayant une déficience intellectuelle, les minorités ethniques ou les populations de milieux défavorisés (Bosma & Resing, 2006; Guthke & Beckmann, 2000) puisque ces tests sont normés sur la population générale et sont fondés sur l'affirmation que toutes les personnes ont reçu les mêmes opportunités d'apprentissage. Par conséquent, les personnes déficientes obtiennent généralement des performances faibles à ce type de tests.

Toutes ces insatisfactions ont mené certains chercheurs à utiliser des tests d'apprentissage ou dynamiques. Le principal intérêt de ces tests est non pas de mesurer les différents déficits des individus, mais de situer leur potentiel d'apprentissage (Beckmann, 2006; Resing, 2006). Le but des tests dynamiques est d'intégrer une ou plusieurs phases d'entraînement, un feedback, ou encore des aides en cours de test. Cette procédure permet aux éducateurs et aux autres professionnels d'obtenir une mesure de l'intelligence plus fiable qu'avec les tests de QI et ainsi de ne plus sous-estimer leurs performances (Tzuriel & George, 2009). Cependant, la principale critique adressée aux tests dynamiques est leur manque de standardisation.

D.2 Le Test d'Apprentissage de la Pensée Analogique (TAPA)

Le Test d'Apprentissage de la Pensée Analogique (TAPA) pallie justement au manque de standardisation reproché aux tests dynamiques. Büchel et ses collaborateurs (par ex., Büchel, Schlatter, & Scharnhorst, 1996, 1997) ont créé ce test dynamique en prenant en compte toutes les difficultés rencontrées par les personnes ayant une déficience intellectuelle modérée dans le domaine des tâches analogiques, notamment le fait qu'elles ne comprennent pas systématiquement ce qui leur est demandé. Le TAPA est composé de dix-neuf items analogiques, présentés sur des matrices en bois de format 2 × 2. Les items sont présentés sous une modalité figurative concrète et géométrique, répartis sur deux niveaux de complexité. L'expérimentateur présente les éléments *A*, *B* et *C* et demande au participant de choisir l'élément *D* parmi six possibilités de réponse dans le niveau 1 et parmi huit possibilités dans le niveau 2, une seule étant correcte. Le nombre de relations varie également en fonction du degré de complexité : il s'agit d'inférer deux relations dans le premier niveau, c'est-à-dire une relation entre les éléments *A* et *B* et une autre entre *A* et *C*. Quant au deuxième niveau de complexité, il y a au total trois relations à inférer : deux entre *A* et *B* et une seule entre *A* et *C*. Les relations varient en couleur, taille, forme, orientation, ajout et nombre. Le test a été administré à cinquante-huit adolescents ayant une déficience intellectuelle modérée. Les résultats ont démontré que deux tiers de ces participants ont été capables de résoudre de simples matrices, de premier niveau de complexité, mais pas celles de deuxième niveau de complexité. Afin d'expliquer ces résultats, une hypothèse de surcharge mnésique a été postulée (Büchel, 2006) ; la mémoire limitée des participants les empêcherait de mémoriser plusieurs relations en même temps et les conduirait à obtenir des performances sous-estimant leurs réelles capacités. Nous allons maintenant aborder la thématique de la mémoire dans le chapitre suivant.

E. MÉMOIRE

E.1 Structure de la mémoire

La mémoire a longuement été perçue comme étant formée d'une composante unique. Cependant, les travaux de Waugh et Norman, Atkinson et Shiffrin, ainsi que Baddeley ont modifié cette opinion. Atkinson et Shiffrin (1968) ont proposé le modèle modal qui décrit la structure de la mémoire comme étant composée de trois registres : le registre sensoriel, la mémoire à court terme et la mémoire à long terme.

Ce modèle a perduré quelques années jusqu'à ce que Baddeley et Hitch (1974) suggèrent de remplacer le registre de mémoire à court terme par celui de mémoire de travail. Ce dernier fait référence au stockage de l'information ainsi qu'à son traitement, ce qui résulte d'une double tâche. La mémoire de travail est composée du système exécutif central qui coordonne deux systèmes esclaves, la boucle phonologique, responsable de l'information verbale et le calepin visuo-spatial, responsable de l'information visuelle et spatiale. Plusieurs décennies plus tard, Baddeley (2000) a proposé une quatrième composante, le buffer épisodique, dont la tâche est de créer une connexion entre les trois composantes énoncées ci-avant.

E.2 Capacités en mémoire de travail

De nos jours, l'influence de la mémoire de travail dans de nombreuses tâches est largement reconnue, comme dans l'écriture, l'apprentissage, l'orientation, l'arithmétique, etc. (p.ex., Alloway, Elliott, & Place, 2010; Alloway, Gathercole, & Elliott, 2010; Engle & Conway, 1998; Engle, Kane & Tuholski, 1999). Par conséquent, de faibles capacités en mémoire de travail sont souvent liées à des difficultés académiques et à un comportement inattentif en classe (p.ex., Cowan & Alloway, 2008; Gathercole & Alloway, 2008; Gathercole *et al*., 2008; Levin, Thurman, & Kiepert, 2010).

Ces difficultés en mémoire de travail peuvent être surmontées, notamment grâce à un entraînement ou par l'utilisation de stratégies. De nombreux chercheurs ont montré une amélioration des performances chez les personnes déficientes grâce à l'utilisation de mémoires externes (p.ex., Bray, Fletcher, & Turner, 1997; Bray, Huffman, & Fletcher, 1999; De Beni & Moè, 1998; Fletcher, Huffman, & Bray, 2003 ; Rinaldi, 2005).

E.3 Empan mnésique chez les personnes ordinaires et déficientes

La capacité de la mémoire de travail est limitée et ne peut traiter qu'un nombre réduit d'items en même temps. Plusieurs auteurs ont défini l'étendue de l'empan mnésique pour les personnes adultes ordinaires : selon Miller (1956), cette capacité est de 7±2 informations ; Ericsson et Kintsch (1995) mentionnent une capacité de 4 informations ; pour Cowan (2001), l'empan mnésique a une capacité de 4±1 informations. Chez les personnes déficientes intellectuellement, l'empan mnésique est moindre, certains chercheurs ayant prouvé que la performance en mémoire de travail était fortement liée à la sévérité de la déficience (p.ex., Henry, 2001; Mäehler & Schuchardt, 2009; Schuchardt, Gebhardt, & Mäehler, 2010). Selon Hulme et Mackenzie (1992), l'empan mnésique des personnes déficientes est limité à environ 2-3 éléments.

L'empan mnésique des individus est en général mesuré par des doubles tâches, qui nécessitent de traiter des informations tout en en mémorisant d'autres. Comme évoqué précédemment à l'égard des tests de QI, les doubles tâches ne sont pas toujours adaptées aux personnes déficientes. Afin de remédier à cela, Lanfranchi, Cornoldi, et Vianello (2004) ont créé des tâches de mémoire de travail verbales et visuo-spatiales spécialement pour les personnes déficientes, tâches que nous avons utilisées dans cette thèse (voir Annexes pour une description complète de ces tâches).

E.4 Mémoire de travail et raisonnement analogique

Plusieurs auteurs ont suggéré un lien fort entre la mémoire de travail et l'intelligence (p.ex., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Embretson, 1995, 1998; Süβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002), ainsi qu'entre la mémoire de travail et le raisonnement analogique (p.ex., Carpenter *et al*., 1990; Engle, Tuholski, Laughlin, & Conway, 1999). Résoudre une analogie nécessite de se représenter chaque partie de la matrice et de construire un lien entre les éléments qui la composent, chaque étape nécessitant la mémoire de travail (Morrison, 2005).

Les personnes déficientes ne peuvent pas toujours stocker les informations tout en exécutant une autre tâche, ce qui les conduit souvent à perdre une partie des informations. En conséquent, ils abandonnent souvent la tâche en raison d'une surcharge mnésique (Alloway *et al.,* 2009). Cependant, une telle surcharge peut être évitée ou réduite à l'aide de mémoires externes, ce que nous allons démontrer dans le prochain chapitre par la description de notre test, le MAC-R.

F. MESURE DE L'APPRENTISSAGE PAR LES NOUVELLES TECHNOLOGIES

F.1 L'utilisation d'ordinateurs dans l'éducation traditionnelle et dans l'éducation spéciale

Depuis leur apparition dans les écoles, les ordinateurs sont désormais utilisés pour enseigner une variété d'habiletés, telles que la résolution de problèmes ou l'arithmétique (Mastropieri, Scruggs, & Shiah, 1997). En considérant que les ordinateurs offrent des activités multiples, les chercheurs ont aussi commencé à les utiliser avec des populations spéciales, afin d'améliorer la qualité de vie des élèves ayant une déficience intellectuelle ou des difficultés développementales (Foshay & Ludlow, 2005).

Ramdoss et Shogren (2009) ont passé en revue vingt-sept études rapportant l'utilisation de l'ordinateur avec des personnes déficientes. La majorité de ces études a suggéré que les interventions utilisant la technologie de l'ordinateur se sont montrées efficaces en améliorant les habiletés fonctionnelles des participants, comme le langage et la communication, les habiletés sociales, ou les performances académiques.

F.2 Avantages et inconvénients d'utiliser la technologie informatique avec les personnes déficientes

Plusieurs chercheurs ont comparé un enseignement dispensé de manière traditionnelle avec un autre dispensé sur ordinateur chez des élèves déficients. Ils ont rapporté une nette préférence pour la technologie (p.ex., Fletcher-Flinn & Gravatt, 1995; McArthur, Haynes, Malouf, Harris, & Owings, 1990), ce qui a été corroboré par de meilleures performances avec ce support plutôt qu'avec le support traditionnel (p.ex., Bosseler & Massaro, 2003 ; Fitzgerald & Koury, 1996 ; Shiah, Mastropieri, & Scruggs, 1995; Woodward & Rieth, 1997).

La technologie offerte par l'ordinateur présente certains avantages pour les personnes déficientes, notamment une augmentation de l'attention (Lee, McGee, & Ungar, 2001b) et de la motivation (p.ex., Bernard-Opitz, Sriram, & Nakhoda-Sapuan, 2001; Foshay & Ludlow, 2005; Hetzroni & Tannous, 2004; Standen, Brown, & Cromby, 2001). Cependant, l'ordinateur présente également certains inconvénients pour les personnes déficientes, qui manquent souvent des connaissances suffisantes pour l'utiliser à bon escient (Wehmeyer, 1998). De plus, ces personnes sont souvent caractérisées par un déficit en motricité fine, ce qui complexifie l'utilisation adéquate de la souris informatique (Hartman, Houwen, Scherder, & Visscher, 2010), ce qui a également été trouvé chez des enfants à développement typique, spécialement les enfants d'âge préscolaire n'ayant pas encore appris à écrire (Donker & Reitsma, 2007). Ce déficit peut être annihilé grâce à l'utilisation d'ordinateurs composés d'un écran tactile. En effet, ce support permet aux utilisateurs d'exécuter des mouvements qui ne doivent pas être aussi précis qu'avec une souris informatique (Foshay & Ludlow, 2005; Stock, Davies, Davies, & Wehmeyer, 2006).

Les Matrices Analogiques de Construction (MAC), un test analogique informatisé que nous allons décrire ci-après, comporte plusieurs avantages pour mesurer le niveau de raisonnement analogique chez les personnes déficientes, dont la présentation des items sur écran tactile.

F.3 Les Matrices Analogiques de Construction (MAC)

Comme exposé précédemment, le TAPA avait fait l'objet d'une hypothèse de surcharge mnésique, puisque les participants avaient été capables de résoudre des matrices composées de deux relations, mais non de trois. Afin d'approfondir cette hypothèse de surcharge mnésique, le MAC (Angeretas & Gonzalez, 2002), un test analogique informatisé, a été créé, réparti sur sept niveaux de complexité. Contrairement au TAPA, les analogies n'étaient plus présentées sur une matrice en bois, mais sur un écran tactile. Les participants ne devaient plus choisir la bonne réponse parmi plusieurs propositions, mais la construire en choisissant des éléments disponibles en permanence en-dessous de la matrice. Le MAC avait l'avantage de permettre aux participants de construire la réponse pas à pas. Une fois touchés, les éléments glissaient à la bonne place, représentant par là-même des mémoires externes. Ainsi, dès que le participant avait considéré une relation, il pouvait traiter la suivante, sans devoir mémoriser la précédente. Par conséquent, la surcharge de la mémoire pouvait être réduite et les performances améliorées (Büchel, 2006).

Les résultats de l'étude ont montré que les trente-six participants ayant une déficience intellectuelle modérée, testés à la fois par le TAPA et le MAC, ont été capables de résoudre des analogies d'un degré de complexité plus élevé dans le MAC. Toutefois, plusieurs critiques ont été avancées. Premièrement, l'aspect visuel des items a été critiqué, car il n'y avait pas d'uniformité dans le design : certains items étaient créés à partir de photos, d'autres à partir de dessins et les éléments n'étaient pas toujours reconnaissables ; deuxièmement, l'ordinateur et son écran tactile pouvaient être considérés comme plus motivants que la matrice en bois, ce qui pouvait justifier de meilleures performances dans le MAC. Enfin, une étude d'évaluation a montré que les niveaux de complexité théorique ne correspondaient pas aux niveaux de difficulté empirique (Büchel, 2006), certains items du troisième niveau de complexité étaient plus difficiles à résoudre que des items du septième niveau de complexité.

Les critiques énoncées à l'encontre du MAC ont fait l'objet d'une révision représentée par le MAC-version révisée (MAC-R) que nous avons conçu pour cette thèse et que nous allons décrire après l'exposition succincte des hypothèses et questions de recherche.

G. METHODE

G.1Questions de recherche et hypothèses

Q.R.1. Dans quelle proportion les performances aux tâches de mémoire de travail, de mémoire à court terme et aux Matrices Progressives Colorées de Raven déterminent-ils la performance au MAC-R chez les enfants à développement typique et chez les participants ayant une déficience intellectuelle ?

H1. Nous faisons l'hypothèse qu'un lien existe entre la mémoire de travail et le raisonnement analogique par rapport à la version de construction et à la version classique. Comme nous supposons que la version de construction décharge la mémoire, la mémoire de travail devrait moins contribuer aux performances des participants dans cette version que dans la version classique.

Q.R.2. Quelle est la validité du MAC-R ? Comment le lien entre la difficulté empirique des items et les niveaux de complexité est exprimé, en termes de nombre de relations et de temps passé à résoudre les items ?

H2. Puisque les versions de construction et classique du MAC-R mesurent toutes deux le raisonnement analogique, nous postulons une corrélation positive entre les deux versions. De plus, comme les Matrices Progressives Colorées de Raven mesurent également le raisonnement analogique, nous postulons une corrélation positive entre ce test et chacune des versions du MAC-R.

H3. Nous faisons l'hypothèse que la probabilité de réussir un item d'un degré de difficulté est plus élevée que de réussir un item du niveau supérieur, car il y a toujours une relation de plus à traiter.

H4. Nous faisons l'hypothèse que, dans les deux versions, le temps passé à résoudre les items augmentera d'un niveau de complexité au suivant. Nous nous attendons à trouver une association linéaire entre le temps et le niveau de complexité car nous supposons que plus le test deviendra difficile, plus les participants passeront de temps à résoudre les analogies.

Q.R.3. Comment le type de version affecte les performances en raisonnement analogique de nos participants, en termes d'utilisation de mémoires externes, nombre d'aides et temps nécessaire pour résoudre les analogies ?

H5a. Nous faisons l'hypothèse que tous les participants obtiendront de meilleurs scores dans la version de construction que dans la version classique, en raison des mémoires externes.

H5b. Nous faisons l'hypothèse que dans la version de construction, les participants ayant une déficience intellectuelle obtiendront des scores proches des enfants de même âge mental, grâce aux mémoires externes.

H6a. Nous postulons que les participants déficients auront besoin de plus d'aides dans les deux versions que les enfants ordinaires.

H6b. Nous faisons l'hypothèse que chaque groupe aura besoin de plus d'aides dans la version classique que dans la version de construction, puisque nous supposons que la version classique sera plus difficile à résoudre.

H7a. Nous postulons que, dans chaque niveau de complexité, les participants déficients passeront plus de temps à résoudre les items que les enfants ordinaires.

H7b. Nous faisons l'hypothèse que les items de construction nécessiteront plus de temps que les items classiques.

Q.R.4. Comme exprimé précédemment, la difficulté des analogies est définie par plusieurs composantes, comme la familiarité des attributs et des relations et le type de relations. À quel point ces composantes influenceront les performances de nos participants ?

H8. Nous faisons l'hypothèse que la majorité de nos participants raisonnera par analogie et non par association, car toutes nos analogies ont été conçues avec des relations familières.

H9. Nous postulons que, dans les deux versions, les items perceptuels seront mieux réussis que les items conceptuels.

G.2 Instruments

Afin d'évaluer les performances de nos participants, nous avons utilisé plusieurs instruments. Premièrement, nous leur avons administré les Matrices Progressives Colorées de Raven (Raven, Court, & Raven, 1990), afin d'obtenir une mesure de raisonnement analogique général concernant nos participants. Ensuite, nous leur avons administré les tâches de mémoire à court terme et de mémoire de travail décrites précédemment (Lanfranchi *et al.*, 2004), afin de connaître l'étendue de leur mémoire.

Enfin, nous leur avons administré les deux versions de notre test MAC-R[1], que nous allons mieux décrire ci-dessous. Nous avons exposé les critiques faites à l'encontre du MAC,

[1] Le MAC-R est constitué uniquement de la version de construction révisée provenant du MAC. La version classique que nous avons créée est une version de contrôle pour tester l'hypothèse de surcharge mnésique. Cependant, pour une simplification des termes, nous allons désigner ci-après le MAC-R comme composé de la version de construction ET de la version classique.

critiques que nous avons tenté d'éliminer. Notre nouveau test est composé de deux versions proposées sur le même support, c'est-à-dire l'ordinateur avec écran tactile, ce qui élimine la première critique selon laquelle le TAPA et le MAC n'étaient pas comparables en raison de leur support différent. Deuxièmement, l'aspect des items a été amélioré, puisqu'une artiste professionnelle (Borel, 2008) a dessiné tous les items sous notre supervision. Troisièmement, nous avons amélioré la relation entre difficulté empirique et théorique, en augmentant le nombre de relations au fur et à mesure de la complexité du test.

Chaque version est composée de matrices analogiques en format 2 × 2 dans une modalité figurative concrète. Dans la version de construction, la réponse *D* doit être construite avec des éléments disponibles en permanence au bas de l'écran, tandis que dans la version classique, elle devra être choisie parmi plusieurs possibilités de réponse, une seule étant correcte. De plus, parmi les éléments ou images de réponse, se trouvent une ou deux associations afin de répondre à l'une de nos hypothèses.

Chaque version est composée de quatre niveaux de complexité, caractérisés par le nombre de relations impliquées dans les matrices. Les participants sont confrontés à des matrices présentées sur écran tactile, où ils perçoivent les termes *A*, *B* et *C*. La réponse *D* est à trouver en inférant les relations présentes entre ces trois éléments. Dans le premier niveau de complexité, il s'agit d'inférer une relation entre les éléments *A* et *B* et une entre les éléments *A* et *C* ; dans le deuxième niveau, trois relations sont à inférer : deux entre les éléments *A* et *B* et une entre *A* et *C* ; dans le troisième niveau, il y a quatre relations à inférer, dont trois entre les éléments *A* et *B* et une seule entre *A* et *C* ; enfin, dans le quatrième niveau de complexité, cinq relations sont à inférer, dont trois entre les éléments *A* et *B* et deux entre *A* et *C*. Afin d'éviter de possibles frustrations chez nos participants, pas plus de cinq relations seront utilisées, conformément à leur empan mnésique limité. Le total des items se monte à seize, dont quatre items par niveau de complexité.

Les items de test sont précédés par huit items d'entraînement, permettant aux participants de se familiariser avec le matériel (écran tactile) et avec la demande de la tâche. De plus, nous avons dûment vérifié, dans une étude pilote, que les relations utilisées telles que la couleur, la forme, la taille, le type d'objet, le genre, etc., étaient connues de notre population (Borel, 2008). En outre, les participants ont la possibilité d'essayer de résoudre chaque item une seconde fois s'ils échouent lors de leur première tentative, recevant alors une aide standardisée de type « Tu as vu que la couleur avait changé entre *A* et *B*, mais regarde bien ce qui change entre *A* et *C* » (voir Annexes pour une description complète de ces aides standardisées).

Chaque version a été administrée à chaque participant, d'après un ordre contrebalancé, avec un écart de huit semaines entre les deux versions. En ce qui concerne la notation des items, nous avons décidé d'attribuer un point par relation correcte, ce qui donne un total de cinquante-six points, correspondant aux cinquante-six relations du test comme expliqué précédemment. Si nous avons choisi cette manière de coter, c'est afin de valoriser le raisonnement de nos participants. En effet, si nous avions décidé d'attribuer un point pour un item entièrement correct et zéro point pour un item entièrement faux, ce qui était notre intention initiale, nous n'aurions pas pu comptabiliser les réponses partiellement correctes comme par exemple deux relations correctes sur un total de quatre.

G.3 Population

Notre échantillon est composé d'un groupe d'adolescents ayant une déficience intellectuelle modérée (*n* = 26 ; âge chronologique : 12-16 ans ; âge mental : 4-7 ans), provenant de deux institutions de la ville de Genève, dénommé GDI pour « groupe déficience intellectuelle », auquel nous avons administré les Matrices Progressives Colorées de Raven, ainsi que les tâches de mémoire (mémoire à court terme et mémoire de travail). Sur la base des scores obtenus, deux types de groupe ont émergé : l'un avec un âge mental entre 7 et 8 ans (GDI 1 ; N = 13) et l'autre avec un âge mental entre 4 et 6 ans (GDI 2 ; N = 13). Malgré notre demande auprès des institutions de ne disposer que d'adolescents ayant une déficience intellectuelle modérée, il semblerait que d'après ces groupes, il n'y en n'ait qu'un avec une déficience modérée, l'autre ayant une déficience légère.

D'après ces résultats, nous avons sélectionné un groupe contrôle composé d'enfants à développement typique du même âge mental (*n* = 32), provenant de plusieurs écoles de la même ville, appelé GDT pour « groupe à développement typique ». Les enfants ont été appariés sur la base des mêmes tests que cités précédemment, ce qui a résulté de deux groupes également : l'un composé des enfants entre 4 et 6 ans (GDT 1 ; N = 18) et l'autre d'enfants entre 7 et 8 ans (GDT 2 ; N = 14).

H. RESULTATS ET DISCUSSION

Nous avons effectué différentes analyses avec le logiciel SPSS (version 17.0). Ces analyses n'ont pas pris en compte les huit items d'entraînement du MAC-R, car ils ont été créés afin de familiariser les participants avec le matériel et avec les demandes de la tâche. Nous allons présenter ici uniquement les principaux résultats, les autres étant présentés dans le document original en anglais.

H.1Résultats et discussion concernant la première question de recherche

Nos premiers résultats ont confirmé un lien entre les scores aux Matrices Progressives Colorées de Raven et le raisonnement analogique, ainsi qu'entre la mémoire et le raisonnement analogique. Nos analyses signifiaient que plus les performances des participants au Raven étaient élevées, plus grand était leur succès en raisonnement analogique ; de même, plus leur mémoire était grande, meilleur était leur succès en matière de raisonnement analogique.

Ces résultats ont confirmé le travail de plusieurs chercheurs ayant découvert une forte relation entre la mémoire et le raisonnement (p.ex., Cho, Holyoak, & Cannon, 2007; Conway *et al.*, 2002; Carpenter *et al.*, 1990). Cependant, si nous contrastons les résultats de chaque groupe, nous avons remarqué que les performances au Raven ont prédit de manière significative la performance en raisonnement analogique des enfants ordinaires dans les deux versions ; par contre, ce sont les tâches de mémoire à court terme qui ont prédit de manière significative la performance en raisonnement analogique des individus ayant une déficience intellectuelle, et ce dans les deux versions. Les tâches en mémoire de travail n'ont pas prédit la réussite au MAC-R, ni pour les enfants ordinaires, ni pour les participants déficients, et ce dans les deux versions. Ce dernier résultat pourrait signifier que les participants n'ont pas utilisé leur mémoire de travail pour résoudre les analogies, peut-être à cause du trop grand nombre d'informations à traiter qui allait au-delà de la capacité de leur empan mnésique (p.ex., Just & Carpenter, 1992; McConaghy & Kirby, 1987; Shah & Miyake, 1999), ou parce qu'ils ne possédaient pas la connaissance et les habiletés suffisantes pour utiliser leur mémoire de travail à bon escient (Ericsson & Kintsch, 1995).

De plus, nous avions émis l'hypothèse que les performances dans les tâches de mémoire contribueraient moins à la performance des participants dans la version de construction que dans la version classique, puisque la première comportait des mémoires externes. Cette hypothèse a été confirmée car les corrélations par rapport à la mémoire de travail et à la mémoire à court terme étaient plus élevées dans la version classique que dans la version de construction, et ce pour tous les participants. Ceci était cohérent avec notre théorie : puisque la version de construction était supposée décharger la mémoire, il était donc logique que la mémoire joue un rôle mineur dans cette version par rapport à la version classique, où la mémoire est surchargée.

H.2 Résultats et discussion concernant la deuxième question de recherche

Nous avions postulé une corrélation positive entre les deux versions du MAC-R, comme elles mesuraient toutes deux le raisonnement analogique. Ceci a été confirmé pour tous les groupes, excepté le GDI1. En d'autres mots, plus les participants avaient du succès dans une version, plus ils en avaient dans l'autre.

De plus, nous avons également mesuré la validité concurrente du MAC-R par rapport aux Matrices Progressives Colorées de Raven. Les données ont révélé des corrélations positives entre chaque version du MAC-R et le Raven, mais ces corrélations étaient plus élevées dans la version classique. Ceci n'était pas surprenant car cette version présentait les matrices et les solutions de réponse de la même manière que le Raven. Par ailleurs, les corrélations obtenues entre chacune des versions du MAC-R et le Raven auraient pu être plus fortes si les tests avaient été plus similaires. Par exemple, le MAC-R proposait des aides en cours de test, ce qui n'était pas le cas du Raven.

Nos résultats ont également confirmé l'hypothèse selon laquelle les scores des participants ont augmenté selon les niveaux de complexité, avec un pourcentage de réussite décroissant. Par contre, nous avons remarqué un effet plafond pour les deux groupes ayant l'âge mental le plus élevé. Cet effet plafond n'est pas surprenant, car comme Siegler et Svetina (2002) l'ont démontré, les items comportant moins de six relations, sont relativement faciles à résoudre pour les enfants de huit ans. Par ailleurs, cet effet plafond pourrait aussi être dû à notre procédure de score qui attribue un point par relation correcte. Cette procédure donne une indication sur le nombre de relations que chaque participant a pu traiter, ce qui permet d'avoir une indication de l'étendue de leur empan mnésique.

Nous avons également trouvé une association linéaire entre le temps passé à résoudre les items et les niveaux de complexité. Plus le test devenait difficile, plus les participants avaient besoin de temps pour résoudre les analogies, ce qui était attendu étant donné qu'il y avait à chaque fois une relation de plus à traiter. Ces résultats ont corroboré ceux de plusieurs auteurs affirmant que le temps augmentait selon le nombre d'éléments impliqués dans les analogies (p.ex., Arendasy & Sommer, 2005; Bethell-Fox, Lohman, & Snow, 1984; Mulholland *et al.*, 1980; Sternberg, 1977a).

H.3 Résultats et discussion concernant la troisième question de recherche

Notre hypothèse, selon laquelle tous les participants obtiendraient de meilleurs scores dans la version de construction que dans la version classique, n'a été confirmée que pour le groupe ayant une déficience intellectuelle modérée, indiquant que les mémoires externes n'ont été bénéfiques que pour ce groupe, mais pas pour les autres.

Deuxièmement, nous avions supposé que dans la version de construction, les participants ayant une déficience intellectuelle obtiendraient des scores proches de ceux des enfants ordinaires, en raison des mémoires externes. Nos résultats ont confirmé des performances similaires entre le GDT1 et le GDI2 et entre le GDT2 et le GDI1, autrement dit entre les groupes partageant le même âge mental.

Troisièmement, nous avions émis l'hypothèse que les participants ayant une déficience intellectuelle auraient besoin de plus d'aides que les enfants ordinaires : ceci n'a pas été confirmé. De plus, nous avions postulé que tous les participants auraient besoin de plus d'aides dans la version classique que dans la version de construction, ce qui n'a été confirmé que pour le GDI1.

Enfin, nos résultats ont montré que pour les niveaux 3 et 4, les participants ayant une déficience intellectuelle n'ont pas passé plus de temps que les enfants ordinaires pour résoudre les analogies. Par contre, notre hypothèse a été confirmée pour les niveaux 1 et 2. Par ailleurs, les items de construction ont nécessité plus de temps que les items classiques, comme nous l'avions postulé.

H.4Résultats et discussion concernant la quatrième question de recherche

La majorité des participants a effectivement raisonné par analogie et non par association, ce qui a confirmé les résultats obtenus par Goswami & Brown (1989, 1990), démontrant que lorsque les analogies étaient composées de relations familières, les jeunes enfants étaient tout à fait capables de raisonner par analogie.

Enfin, nos résultats n'ont pas démontré que les analogies conceptuelles étaient plus difficiles à résoudre que les analogies perceptuelles, ce qui a corroboré les résultats trouvés par Lifshitz, Weiss, Tzuriel, et Tzemach's (2011). Ces derniers ont administré un test composé d'analogies perceptuelles et conceptuelles à des adolescents et adultes ayant une déficience intellectuelle, mais n'ont trouvé aucune différence entre les deux types d'analogies, puisque les deux groupes y ont démontré les mêmes performances.

H.5 Discussion générale

Comme attendu, nos résultats confirment l'idée que la version classique a surchargé davantage la mémoire de nos participants que la version de construction. De manière générale, les performances des deux groupes ayant l'âge mental le plus élevé (i.e. GDT2 et GDI1) ont été meilleures que celles des deux groupes ayant l'âge mental le plus faible (i.e. GDT1 et GDI2) : leurs scores sont plus élevés dans les deux versions, ils ont choisi moins d'associations, ont eu besoin de moins d'aides et ont passé moins de temps pour résoudre les analogies. Cependant, nos résultats suggèrent qu'avec le soutien des mémoires externes, les participants ayant une déficience intellectuelle modérée (i.e. GDI1) ont été capables d'obtenir de meilleures performances que sans ce support, ce qui leur a permis d'atteindre un niveau de performances similaire à celui des enfants de même âge mental.

La version de construction a pu promouvoir une manière plus analytique de résoudre les analogies. Comme les réponses devaient être construites pas à pas, les participants pouvaient traiter une relation après l'autre sans devoir mémoriser les relations déjà prises en considération. Grâce à la stratégie d'utilisation des mémoires externes, ils se concentraient sur une relation à la fois, alors que dans la version classique, ils devaient se concentrer sur une image entière. Par conséquent, la version de construction, avec ses éléments séparés, nécessitait plus de temps pour sa résolution que la version classique. L'implication pratique de la version de construction a consisté dans le fait que la séparation des éléments a été bénéfique pour les participants ayant une déficience intellectuelle modérée, puisqu'ils y ont obtenu de meilleures performances que dans la version classique. De plus, la version de construction leur a permis de dépasser les limites de leur empan mnésique, puisqu'ils ont été capables de traiter jusqu'à cinq relations, alors que leur empan mnésique peut en traiter d'ordinaire deux ou trois.

H.6 Limites de l'étude

Plusieurs limites doivent être reconnues. Premièrement, nous avons mentionné un effet plafond rencontré par les groupes ayant l'âge mental le plus élevé. Cet effet plafond peut être expliqué notamment par notre procédure de score, qui attribue un point par relation correcte, ce qui augmente le nombre de points par rapport à une procédure qui attribuerait un point pour un item entièrement correct et zéro pour un item faux. Cet effet plafond pourrait être réduit par l'ajout de niveaux de complexité supplémentaires. Ainsi, nous saurions jusqu'où les participants seraient capables d'aller selon leurs capacités mnésiques et cela permettrait aux mémoires externes de jouer leur rôle attendu.

Deuxièmement, nous devons être prudents dans l'interprétation des scores, étant donné la petite taille de notre échantillon.

Une troisième limitation concerne les associations présentes dans notre test. Celles-ci ont fait l'objet de nos propres choix et non celui des enfants, ce qui aurait constitué une manière plus fidèle de procéder. Ainsi, nous avons d'ores et déjà conçu une version révisée du MAC-R comprenant des associations choisies par une centaine d'enfants entre 4 et 7 ans.

I. CONCLUSION

Nos résultats ont des conséquences pédagogiques pour les personnes ayant une déficience intellectuelle modérée, car ils démontrent que ces dernières sont capables de résoudre des matrices analogiques de différents niveaux de complexité et qu'elles peuvent obtenir des résultats proches ou égaux de ceux d'enfants de même âge mental lorsque les tâches leur offrent la possibilité d'utiliser des mémoires externes.

Nous supposons donc qu'une procédure comportant des mémoires externes favorise de meilleures performances pour cette population dans le domaine du raisonnement analogique. Les implications pédagogiques de ce type d'études vont à l'encontre de ce qui est généralement pensé par les professionnels : les personnes ayant une déficience intellectuelle modérée sont capables d'atteindre des niveaux de raisonnement abstrait plus élevés que ce qu'on les croit habituellement capables de réaliser (Resing, 2000).

En outre, le support informatique s'est révélé attrayant pour tous nos participants, car ils pouvaient agir sur les éléments présentés (en les touchant avec leur doigt, ils les voyaient glisser au bon endroit). De nombreux participants ayant une déficience intellectuelle présentaient également une motricité fine qui n'était pas très développée, ce qui les empêchait de manipuler la souris informatique. Notre test leur a permis d'avoir un effet concret sur des éléments sans devoir être très précis. Cette motivation était aussi accompagnée d'un intérêt pour la tâche : nous avons remarqué que l'attention de tous nos participants a été maintenue au-delà de nos attentes. En effet, les éducateurs et enseignants, selon leurs dires, parvenaient à maintenir l'attention de leurs élèves durant environ dix à quinze minutes ; or, chaque version de notre test durait trente minutes. Tous les participants sont parvenus au terme de chaque version, ce qui représente un maintien de l'attention deux à trois fois supérieur à l'attention maintenue dans les tâches quotidiennes. Cependant, nous n'avons pas comparé les deux types de tâches de manière empirique, nous ne pouvons affirmer la supériorité de l'ordinateur sur les tâches quotidiennes que d'après les dires des éducateurs. Nos regards doivent être tournés vers l'essor des nouvelles technologies, qui ont beaucoup à offrir, surtout pour les personnes ayant des capacités moindres par rapport aux personnes ordinaires.

ENGLISH DISSERTATION

1. INTRODUCTION

This thesis project focuses on the evaluation of a memory overload hypothesis in analogical reasoning tasks. It is said that individuals with moderate intellectual disability (mental age: 4-7 years) are confronted to a memory overload when they have to treat more than two relations in analogical matrices, which hamper them to be successful (Büchel, 2006). In order to test this assumption, we created a computerized dynamic test composed of a construction version, which is supposed to offload the memory, and a control version, which is supposed to overload the memory.

Analogical reasoning, as part of inductive reasoning is considered to be an important mechanism in learning and problem-solving (e.g., Gentner, 2003; Gentner, Holyoak, & Kokinov, 2001; Hofstadter, 2001; Holyoak, 2005) and has been considered for many years as a central component of intelligence (e.g., Goswami, 2001, 2002; Sternberg, 1977a). In order to solve inductive reasoning problems, a process of systematic comparison is necessary, including looking for similarities and/or differences between attributes of a task and relations between these attributes (e.g., Klauer & Phye, 2008). Analogical reasoning is one of the aspects of inductive reasoning, a process that is also called relational reasoning (e.g., Goswami, 2008). Most research on the development of analogical reasoning has been done in the field of identifying correspondences between already known problems and novel ones and finding relations between words, pictures and forms, to be matched with other ones (e.g., Gentner, 1989; Gentner & Holyoak, 1997; Gentner, Loewenstein, & Thompson, 2003).

A distinction has frequently been made between classical analogies and problem-solving analogies. In problem-solving analogies, a person needs to solve a problem by using an analogy known from a previously experienced problem or situation. Classical analogies are often presented in the form of *A:B=C:?* (open vs. closed format). A person is then required to find the fourth element of a group (*D*), by inducing the relationship between the first two elements of the task (*A:B*) and applying it to the third element (*C*).

In traditional tests (also called static tests), the classic analogy represents the most used format. For instance, the analogy *Tree : Forest :: Room :* (a. *Door*, b. *Window*, c. *House*, d. *Kitchen*) requires the coordination of several component processes, such as encoding the *A*, *B*, and *C* terms (*Tree, Forest*, *Room*), inducing the relation between the *A* and *B* terms (here, a part-whole relation), applying the relation from the *C* term to the possible answers (here, *Room* is a part of a *House*), and responding (Robins & Mayer, 1993). In other words, the answer "*D*" can be found by following the rule "A is to B, what C is to D" (Pellegrino, 1985).

The static tests assess the cognitive or intellectual functioning of individuals with and without intellectual disability. These tests are characterized by fully standardized instructions and no feedback. Test scores allow individuals to be positioned in relation to a reference population and thus show that "one individual is worse or better than another on some performance that is related to a criterion performance such as academic achievement (Pellegrino & Glaser, 1980, p.178). Nevertheless, more and more theorists and professionals agree on the fact that static tests do not give an adequate picture of the cognitive intellectual potential of an individual. These tests do not provide a reliable prediction of future learning. Furthermore, most of them do not provide any clue about the types of interventions that would be best suited for improvement (e.g., Lidz & Elliott, 2000; Resing, 1997, 2000).

Despite the fact that these tests fall short their goal, they still remain the preferred procedure in intelligence testing mostly because they are easy to apply and psychologists are predominantly trained in the use of static tests (Sternberg, 1985). On the other hand, dynamic procedures used to test individuals' abilities have proved to be more effective (Grigorenko & Sternberg, 1998), especially among individuals with intellectual disability (e.g., Budoff, 1987). Nevertheless, dynamic assessment and testing procedures have been criticized, amongst other reasons, because of a lack of standardization.

Static analogical tests are not adequate to assess analogical reasoning abilities in individuals with intellectual disability, as these persons sometimes do not understand the proposed task and what they are asked to do, even if some familiarization examples are provided. Since mediation or verbal exchanges between experimenters and participants are not allowed, examinees cannot receive additional explanations and hence are unable to solve the tasks. Moreover, they are often considered to be a homogeneous group that cannot do better than what they show on traditional analogical reasoning tests, and their cognitive abilities are therefore underestimated (Resing, 2000).

In addition, static tests are mostly presented in a paper-and-pencil format. Several authors have shown that tests presented on a computer are more effective for individuals with moderate intellectual disability than with paper-and-pencil tests (e.g., Bosseler & Massaro, 2003; Fletcher-Flinn & Gravatt, 1995; Hetzroni & Tannous, 2004; McArthur, Haynes, Malouf, Harris, & Owings, 1990). Students with intellectual disability often have motor, perceptual, and representational deficits which hamper them from manipulating the computer mouse. It has been suggested that laptop computers are the most promising devices for individuals with intellectual disability (e.g., Davies, Stock, & Wehmeyer, 2002, 2004; Stock, Davies, Davies, & Wehmeyer, 2006), and particularly those using a touch screen (Foshay & Ludlow, 2005) because with such a device their movements do not need to be very precise. Besides, this device improves the motivation and the attention span of participants with intellectual disability (e.g., Lee, McGee, & Ungar, 2001a).

By taking into account criticisms regarding both static tests and dynamic assessment (i.e., lack of standardization), two studies (i.e., Büchel, Schlatter, & Scharnhorst, 1997; Angeretas & Gonzalez, 2002) concerning analogical reasoning have been designed especially for students with moderate to severe intellectual disability (IQ: 35 to 55). The first study reported on the use of the Analogical Reasoning Learning Test (ARLT), a manipulative test composed of wooden blocks with two levels of complexity. The participants were confronted with the *A*, *B*, and *C* parts of the matrix and had to choose the answer *D* among 6 or 8 possibilities. If the participants failed to find the correct answer, they received specific or general hints. As for the second study, it reported on the use of the Construction of Analogical Matrices (CAM), a computerized test composed of a touch screen with 7 levels of complexity. The major distinctive feature of this test was that the participants had to solve the analogies by constructing the correct answer part by part and no longer by choosing the right picture among a set of alternatives like in the first study. The potential elements constituting the answer were permanently available on the lower part of the screen. They represented external memory hints. Once a participant had discovered a relation and selected an element with his/her finger, he/she could consider a second relation without having to remember the first one. If the participants failed to find the correct answer, they received specific or general hints.

In Angeretas and Gonzalez's (2002) study, thirty-six participants with moderate to severe intellectual disability received both tests. The results of the ARLT showed that two thirds of the participants were not able to solve analogies composed of three relations, whereas the same participants were able to solve items of a higher complexity level in the CAM study. In order to explain these results, Büchel (2006) hypothesized that the participants did not have a deficit in analogical reasoning but suffer from a memory overload, which kept them from memorizing several relations at the same time. The construction version of the CAM, which proposed a step-by-step resolution, could have allowed the participants to offload their memory. This procedure gave better performances than in the ARLT, which required a global resolution. In sum, the CAM was considered more advantageous than the ARLT for individuals with moderate to severe intellectual disability. However, the positive results of Angerats and Gonzalez's (2002) study were limited for several reasons. It is possible that the results were higher in the CAM potentially because the touch screen was considered more interesting and induced higher engagement by the participants than the wooden blocks of the ARLT. In addition, both tests were not presented in the same format (computer versus wooden blocks), which reduced the value of the comparison.

The present study continues on from the Büchel *et al*. (1997) and Angeretas and Gonzalez's (2002; see also Büchel, 2006) studies. It represents an elaboration of their studies, first by taking into account the before-mentioned criticisms, and second, by extending the research questions. For this study, we designed a new test, the Revised-Construction of Analogical Matrices Test (CAM-R) composed of a construction version, which proposes to construct the answer part by part (same format as in the CAM) by using elements permanently available at the bottom of the screen, thereby constituting external memories. This version will be opposed to a control version, called classic version, which proposes to select the correct answer among several alternatives (same format as in the ARLT).

Although the CAM-R[2] is not a proper dynamic testing as described above, it can be considered as a dynamic test procedure in some aspects: it offers feedback between the first and the second trial, which allows the participants to correct their wrong answer and to try to solve each item a second time; the feedback is standardized and assesses the participants' reasoning under equal conditions (i.e., receiving the same instructions in the same conditions); in addition, the CAM-R proposed a training phase in order to familiarize the participants with the material (i.e., the touch screen) and with the task demands (i.e., to reason by analogy).

[2] The CAM-R is only composed of the construction version, because the classic version represents a control version. However, in order to simplify the terms, we will refer to the CAM-R as comprising the construction version AND the classic version.

2. RATIONALE FOR THE PRESENT RESEARCH

The main objective of this research is to test whether or not a reduction of memory overload in an analogical reasoning situation can enhance the performances in individuals with moderate intellectual disability and in young children (4-7 year-olds). We assume that an attractive device (i.e, touch screen and familiar pictures) and external memories provide more favorable conditions for a better performance in analogical reasoning than traditional procedures. Due to these conditions, participants with moderate intellectual disability and young children might be able to overtake the limits of their memory span.

A second objective is to study whether or not students or groups of students with intellectual disability, due to external memory hints, are able to produce the same performances as children of the same mental age who do not have intellectual disability. The abilities of individuals with intellectual disability are too often underestimated. The results of this study could bring out more adequate views on their performances.

Other objectives consist in: avoiding the criticisms made against the CAM test with the creation of a new analogical reasoning test (i.e., the CAM-R); checking the participants' performances in terms of time spent and help needed for solving the analogies; checking the kind of reasoning used by the participants (reasoning by analogy vs. by association); and observing the differences between the types of relations used in our items (perceptual vs. conceptual relations).

In the next chapters, we will present a theoretical background for: analogical reasoning, intellectual disability, dynamic assessment, and memory. Then, the following chapter will describe the different uses of computer technologies in traditional and special educations. The chapter concerning the "Method" will describe the several research questions and hypotheses, as well as the several tools used in this dissertation, and a complete description of our own, personally designed analogical reasoning test: the CAM-R; the project design and the population procedure will be presented in this same chapter. Next, we will present the results pertaining specifically to the research questions and the hypotheses; the discussion about the results, as well as the limitations of the study; and finally, we will propose a self-criticism, the future's prospects and possibilities and the conclusion.

3. ANALOGICAL REASONING

3.1 INTRODUCTION

In this chapter, we shortly will define the term analogy and some theories regarding analogical and inductive reasoning. Then we will describe two ways for measuring analogical reasoning: classical analogies and problem-solving analogies. The focus of this chapter, however, will be on the development of analogical reasoning during childhood, and notably, the existing factors explaining the success and failure of young children in analogical reasoning tasks. Finally, we will describe task aspects that, partially, make analogical reasoning more or less difficult.

3.2 DEFINING ANALOGICAL REASONING

Analogical reasoning (AR), as part of inductive thinking, has been defined as “the development of general rules, ideas, or concepts from sets of specific instances or examples » (Pellegrino, 1985, p.195), which requires an individual to reason from particular to general (Sternberg & Gardner, 1983). Klauer (1999) defined inductive reasoning as the comparison of objects (or situations) in terms of similarities and differences with regard to the attributes and relations held in common. Specifically, the author identified 6 classes of inductive reasoning linked to the cognitive processes required for finding the solution: the generalization (to find similarity of attributes), the discrimination (to observe differences among objects or situations with regard to attributes), the cross-classification (2 attributes, at least, must be considered simultaneously), the recognizing relationships (identification of similarities among relations), the differentiating relationships (to recognize the differences among relations and to rule out the wrong objects or situations, which do not fit in with the others) and the system construction problems (to find the solution by applying at least 2 relationships). These 6 classes are linked together because each one can be solved by a common strategy, which is the comparison.

Nowadays, analogy can be found in everyday life in a variety of contexts. Decades ago, Sternberg (1977b, 1977c) mentioned the use of analogy in daily life: for example, when we consider someone’s advice, because it was a good recommendation previously, we are reasoning by analogy. Similarly, we always have to face new persons, new situations, and new phenomena and, thanks to AR, we are able to create similarities between our past experiences and new situations (Colhoun & Gentner, 2009; Gentner & Holyoak, 1997; Goswami, 1998). Analogy can be found in school as well when teachers introduce new material by comparing it to another material that children already know (White & Alexander, 1986). Some researchers demonstrated that AR was fundamental for any reading process (Goswami & Brown, 1990; Snowling, 1994) and for constructing hypotheses (Tzuriel & Flor-Maduel, 2010). During decades, analogies have been used for assessing intelligence (Sternberg, 1977a, 1977b), and they are still used nowadays for that purpose.

3.3 ANALOGICAL REASONING THEORIES

Several researchers proposed theories explaining in what defines AR and the processes that were employed within those definitions. For example, Sternberg developed the componential theory, in that AR components were presumed to assess intelligence (Sternberg, 1979, 1981; Sternberg & Downing, 1982). The author (1977a, 1977b) described 6 components: 1) *encoding* the individual terms of the analogy; 2) *inferring* the relationship between the *A* and *B* terms; 3) *mapping* the relationship between the *A* and *C* terms; 4) *applying* a relation, analogous to the inferred relation, to each possible answer; 5) a *justification* process, which is an optional step; and 6) a *response* process. Sternberg showed that these information-processing components could be used to solve analogical matrices, series completion and classification problems (Sternberg, 1979, 1981; Sternberg & Gardner, 1983)[3].

Other authors proposed similar theories, such as Holyoak and Thagard (1989, 1995, 1997) with their multi-constraint theory. Whatever the theory, the common characteristic lied in the fact that one needs several processes in order to find out the solution of analogies.

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[3] Sternberg recognized that his componential theory of intelligence assessed only one aspect of intelligence. Several years later, he proposed a triarchic theory of intelligence (1985), in which the componential theory was one of the 3 subtheories.

3.4 ASSESSING ANALOGICAL REASONING

AR ability is generally measured by 2 different tasks: classical analogies and problem-solving analogies, which can be verbal, geometric, numerical or pictorial.

The traditional analogy format, usually called the classical analogy, is a system where a person should find the correct answer (*D*) in the equation *A:B=C:? (D)*, by detecting the relationship between the first two elements of the task (*A* and *B*) and applying this relationship to the third element (*C*). For example, if we have "*large*" and "*small*" as the first two elements, and "*elephant*" as the third, we should deduce that the fourth element is "*mouse*". The analogy, *large : small = elephant : mouse*, most of the time displayed as *A : B :: C : D,* is either in linear form or in a 2 × 2 matrix form (Pellegrino, 1985; Sternberg, 1977b).

Another way to measure AR ability is represented by the problem-solving analogy, which can be found in the Gentner's "structure-mapping" theory (1988, 1989). Participants have to map knowledge from a problem that has already been solved (the base) to a new problem (the target) by highlighting the relational similarity between the base and the target (Gentner & Forbus, 2010).

In classical analogies or in problem-solving analogies, the aim is to compare elements (or situations) in terms of similarities and differences, to infer relations between elements (or situations) and to apply these relations, in order to discover the solution (Klauer, 1999; Sternberg & Rifkin, 1979). According to several researchers (e.g., Singer-Freeman, 2005; Holyoak, 1984), there is a major difference between the problem-solving analogy and the classical analogy. Holyoak (1984) stated that "analogy items are simply to be solved for their own sake, whereas in problem solving the base analog must be selected and evaluated with respect to its usefulness in generating an effective solution to the target problem" (p.223). Several authors gave reasons regarding success and failure for both kinds of task.

Success in classical analogies has been attributed to the fact that the participants received instruction on how to compare the first three terms (*A*, *B*, and *C*) in order to find out the *D* term. However, failure in these tasks has been attributed to the late-developing ability to understand higher-order relations (i.e., the relations between the *A* and *C* terms and the *B* and *D* terms; Piaget, Montangero, & Billeter, 1977). Success in problem-solving tasks has been attributed to a process named *the relational similarity constraint*, which is the ability to establish a relationship between the *A*-*B* terms and the *C*-*D* terms. However, failure in this kind of tasks is due to the fact that the participants are not often informed that the solution to the base problem has to be used in order to solve the target problem (Goswami, 1992). Although we exposed both types of tasks, this dissertation will exclusively handle classic analogies in a 2 × 2 matrix form. Therefore, we will mention less and less problem-solving analogies in the following chapters.

Whatever the analogy format, it is assumed that AR ability does not develop in the same manner in young children as it does in older children. The same is true for individuals with or without intellectual disability. Although persons with intellectual disability are the subjects we wish to study in this dissertation, we will start with the development of AR ability in typically developing children, and then focus on AR ability in individuals with intellectual disability (see Chapter 4).

3.5 ANALOGICAL REASONING IN YOUNG CHILDREN

3.5.1 Piaget's developmental theory

Piaget claimed that solving classical analogies required formal-operational reasoning, which did not emerge until early adolescence, at the age of approximately eleven or twelve years (Piaget *et al*., 1977). According to these authors, young children were only able to understand lower-order relations between 2 terms (i.e., relations between the *A* and *B* terms versus the *C* and *D* terms). Only later in development were they able to understand higher-order relations (i.e., the relations between the *A* and *C* terms and the *B* and *D* terms). For instance, in a typical analogy *bird : feathers :: dog : hair*, the lower-order relations are those between *bird* and *feathers* and between *dog* and *hair*. The higher-order relation is the fact that *feathers* and *hair* protect the animals from the cold. The lower-order relations can be deciphered as to keep warm, to enable flight or to distinguish the breed. Piaget presented this kind of analogies to 5 year-old children and asked them why the pairs of terms fitted together. Children gave answers such as “the dog eats the bird, so are the feathers!” (p.118), and thus led Piaget and his collaborators to conclude that the children were too young to understand the higher-order relation. According to these authors, young children, who tended to solve analogies, relied on other reasoning strategies like associative reasoning, a lower-level form of reasoning that did not require the full understanding of higher-order relations. This process of associative reasoning tended to decrease with age, as the use of AR increased with age, which was confirmed by several researchers (e.g., Sternberg & Nigro, 1980).

3.5.2 Associative reasoning

This tendency of young children to rely on associative reasoning is closely linked to thematic relations (Goswami & Brown, 1990). A number of studies reported that in picture sorting tasks young children preferred to relate items by thematic or associative relations (e.g., to relate *fish* with *net*, or *dog* with *bone*) rather than category relations (e.g., to relate *fish* with other fish, or *dog* with other animals) (e.g., Markman & Hutchinson, 1984; Smiley & Brown, 1979). In the same idea, Gentner (1977, 1988, 1989) argued that young children tended to choose a picture that was most similar to the *C* term, reasoning on the basis of *mere appearance similarity,* whereas older children used relational similarity.

The choice of an answer similar to the *C* term was also found in Goldman, Pellegrino, Parseghian, and Sallis' (1982) study, who administered verbal analogies to 8 and 10 year-old children. These authors suggested that the younger children's understanding of the relations was weaker than the older children's understanding, because they choose more possible answers that were highly associated to the *C* term of the analogy. In the same manner, Sternberg and Nigro (1980) compared the performances of 9, 12, 15 year-old children as well as college students (18.5 years) on verbal analogies such as *narrow : wide :: question :? (trial; statement; answer; ask)*. Results showed that children in the two earlier grades (9 and 12 year-olds) relied heavily on association and not on AR, whereas older children (15 year-olds) and college students relied on AR. Similar results were found by Gallagher and Wright (1979).

Goswami (1989, 1991, 1992, 1995) contradicted the results of the above-mentioned authors. She explained that in Piaget's tasks children solved the analogies by using simpler strategies, like *mere appearance similarity* or association because they had no other choice. According to her, young children's problems in solving analogies were not due to their lack of understanding higher-order analogies but to their unfamiliarity with regard to the relations involved in the analogies. In addition, Piaget's tasks frequently involved uncommon relations, such as "steering mechanism" (*bicycle : handlebars :: ship : rudder*), which were unfamiliar to younger children. The same was true for Gallagher and Wright's study (1979), which used relations like "powered by" (*automobile : gas :: sailboat : wind*). Logically, they found that children younger than 12 years of age were unable to solve abstract analogies, based on higher-order processes, and could only solve concrete ones, based on observable characteristics, which was not the case for 12 year-old children.

In the same way, Robertson (1993) changed the original terms in the analogy used by Piaget with more familiar and simpler terms. The results showed, contrary to Piaget's outcomes, that 56% of the 3 year-olds and 80% of the 5 year-olds solved the items. These findings were supported by Richardson and Webster (1996). They compared the performances of young children by comparing abstract analogies composed of geometrical pictures to meaningful analogies composed of familiar pictures. Their results showed that the meaningful analogies were easier to solve than the abstract analogies.

Goswami and Brown (1989, 1990) were very interested in proving the existence of AR ability in young children and their capacity to reason by analogy and not by association. They designed classical analogies based on thematic relations, which were known to be highly attractive to young children, who had to reason about familiar relations, such as: *lives in*, *bird : nest :: dog : dog house*. The *A : B :: C : D* task had to be solved by choosing the right answer among a range of alternatives (distracters): a strong thematic associate of the *C* term (*bone*), a mere appearance match choice (another *dog*), and a category match (*cat*). The thematic relations chosen by the authors represented very strong associations for young children, being highly associated with the *C* term. The mere appearance choice (another *dog*) was chosen to test Gentner's assumption that younger children tempted to solve analogies by choosing a picture that was most similar to the *C* term. The strong thematic associate of the *C* term (bone) was chosen to "test Piaget's and Sternberg's suggestions that children attempt to solve analogies by association" (p.242). Results showed that 4, 5, and 9 year-olds were able to reason by analogy at higher percentages (60%, 65%, and 100% respectively), which contradicted the assumptions of Gentner, Piaget and Sternberg.

Goswami and Brown's point of view was legitimized by many researchers, who asserted that young children were able to reason by analogy in different kinds of tasks, either in classical analogies (e.g., Alexander, Willson, White, & Fuqua, 1987; Alexander *et al.*, 1989; Nippold & Sullivan, 1987; Odom, Astor, & Cunningham, 1975; White & Alexander, 1986), or problem-solving analogies (e.g., Alexander, White, Haensly, & Crimmins-Jeanes, 1987; Brown & Kane, 1988; Brown, Kane, & Echols, 1986; Brown, Kane, & Long, 1989; Gentner, 1977; Holyoak, Junn, & Billman, 1984; Kotovsky & Gentner, 1996). AR ability was even found in toddlers (e.g., Chen, Sanchez, & Campbell, 1997; Crisafi & Brown, 1986; Singer-Freeman, 2005).

3.5.3 Factors explaining young children's low performances in analogical tasks

Many studies demonstrated that young children got lower performances in analogical tasks compared with older children. Several reasons were exposed to justify this statement, such as a cognitive deficit, a lack of instruction, the complexity of the material used, an increase in the time spent for solving the tasks, or the development of the prefrontal regions of the brain.

3.5.3.1 Cognitive deficit

Halford's concern (1987, 1992, 1993) was about the processing load determined by the number of relations involved in the analogies. When more than one relation had to be inferred, Halford stated that the processing load was too extensive for children below 4 to 5 years of age. That might be the reason why children's poor performance on classical analogy tasks had traditionally been attributed to a cognitive deficit representing the inability to treat several relations at the same time (Goswami, 1989). Halford (1984) also argued that the ability to reason about pairs of relations was not available before 7 years of age. Below this age, children should solve the analogies at chance levels.

Nevertheless, Goswami (1995) showed that children as young as 3 years of age could solve pairs of relations when they were familiar to them. With her colleagues (Goswami, Leevers, Pressley, & Wheelwright, 1998), she argued that Halford's (1984) study used left-right relations, which represented difficult relations even for 9 year-olds. She proposed (1992, 2001, 2008) a *relational knowledge hypothesis*, asserting that AR was a capacity available in early infancy but the performances of young children increased with age, as they acquired knowledge about relevant relations. According to this author, young children's difficulty to reason about relations was not determined by the processing load capacity as Halford stated, but rather by the relational knowledge that they possessed, which was also corroborated by other authors (e.g., Abdellatif, Cummings, & Maddux, 2008).

3.5.3.2 Lack of instruction

Singer-Freeman (2005) explained young children's failure by the fact that they did not always know what they had to do in the proposed tasks. The goals were sometimes unclear for them, whereas older children were able to understand them without instruction. For example, in the problem-solving analogies, children did not always know that they had to use the knowledge acquired in the base problem in order to solve the target problem, which was less the case in classic analogies where they were told to use the *A*, *B*, and *C* terms in order to find the *D* term.

Direct instruction has proved to improve participant's performance in AR tasks (Alexander, White, Haensly *et al.*, 1986, 1987; Phye, 1989, 1990, 1991; Robins & Mayer, 1993; Sternberg & Ketron, 1982) and has been assumed to play a key role as showed by Holyoak *et al.* (1984), who have found that only 30% of 11 year-old children were able to solve spontaneously problem-solving analogies, whereas 100% of them were able to do so after they received some instruction.

However, AR performances in young children are possible without any instruction. Tunteler and Resing (2002) examined whether there was any spontaneous analogical problem-solving behavior in 4 year-old children, which meant using a piece of information from one problem in order to solve another problem without any type of help or instruction. Two types of tasks were used in 6 sessions, one story problem and one physical problem with similar solution processes. In 30% of the cases, children were able to detect the relationship between both problems spontaneously, and to select an appropriate tool in order to solve the second problem. Tunteler & Resing (2007) reported the spontaneous use of analogy in 5-8 years-old children and found that this ability improved over time with practice.

3.5.3.3 Material complexity

The use of familiar relations is one possible adjustment that can promote young children's ability to reason analogically. Because researchers used known material, several of them demonstrated that even 3 year-old children were able to reason by analogy (Alexander, Willson, White, & Fuqua, 1987; Bastien-Toniazzo, Blaye, & Cayol, 1997; Holyoak *et al.*, 1984; Pierce & Gholson, 1994; Richland, Morrison, & Holyoak, 2006; Roberston, 1993; Singer-Freeman & Goswami, 2001; Tunteler & Resing, 2002; White & Caropreso, 1989).

Goswami (1991) argued that the analogies used by Sternberg and Rifkin were too difficult for young children. In order to prove the opposite, she designed analogies composed of simple shapes (circles, triangles, squares, diamonds and rectangles), for instance *blue circle with silver stars : blue square with silver stars :: blue circle with silver and gold stars : blue square with silver and gold stars*. Results showed that 6 year-old children were able to solve the analogies, because the higher-order relations were composed of familiar elements. Then, Goswami investigated the same task with 4 year-old children, who also demonstrated similar results.

Nippold and Sullivan (1987) changed the classical appellation "*A is to B as C is to D*" for a more familiar one "*A goes with B and C goes with D*". They gave classical analogies on a 2×2 format to 5, 6, and 7 year-old children. The authors showed that, by adapting task format, 5 to 7 year-old children were able to solve the analogies: 50% for the 5 year-olds, 62% for the 6 year-olds and 67% for the 7 year-olds.

Alexander, Willson, White, and Fuqua (1987) designed the Test of Analogical Reasoning in Children (TARC) composed of sixteen *A : B :: C : D* geometric analogies presented in a game-playing format to 4 and 5 year-old children. The authors assumed the traditionally used paper-and-pencil tasks would be less appropriate for young children than a manipulative game-like situation. They developed a manipulative task composed of blocks varying in shape (rectangle, circle, square, triangle), size (large, small), and color (blue, red, yellow). The problems were presented to 4 and 5 year-old children, among half of them were able to reason analogically, due to the manipulative format. Tzuriel and Klein (1987) also created a game-like situation with the Children's Analogical Thinking Modifiability Test (CATM; Tzuriel & Klein, 1985). Instead of presenting the items like in a matrix format, they used three-dimensional blocks. The manipulation of the blocks and the game-like format demonstrated an increase of the children's motivation and attention to solve the problems.

3.5.3.4 Time component

Differences between young and older children also lie in the time spent for solving the tasks. Several authors proved that young children needed more time than older children (e.g., Alexander, White, Haensly *et al*., 1986; Foorman, Sadowski, & Basen, 1985; Pellegrino, 1985; Sternberg, 1977b; White & Alexander, 1986). Sternberg and Rifkin (1979), for example, proposed analogies to 8, 10, 12, and 19 year-old participants. Results showed that in both experiments the solution time required to solve the analogies decreased across age levels, as well as error rates. This meant that 8 year-old children spent more time and made more errors than 10 year-old children, who in turn spent more time and made more errors than 12 year-old children and so on. Even if both kinds of analogies seemed to be quite similar, they required different strategies: therefore, separable attributes needed to be considered one by one, and they took more time to be solved, whereas integral attributes needed the encoding of all attributes in a single operation. Young children were perhaps not be able to consider an analogy as a whole operation, because they were not able to perform such an encoding procedure, and therefore, had to break down the different terms into several attributes, which took more time.

These experiments are interesting for our own research because both versions of our analogical test (see Chapter 8) are either composed of integral pictures or with separable attributes, which will allow us to compare the performances with those of Sternberg and Rifkin.

3.5.3.5 Contribution of neuroscience

The differences of performance between young and older children in AR can also be interpreted in light of current neuroscience findings. The prefrontal regions are known to develop gradually through childhood, adolescence and adulthood (e.g., Gogtay *et al.*, 2004; O'Donnell, Noseworthy, Levine, & Dennis, 2005), and it is widely assumed that the development of the prefrontal cortex directly influences the ability to represent several rules in problem solving (e.g., Luo *et al*., 2003; Wright, Matlen, Baym, Ferrer, & Bunge, 2008). Recent neuroimaging research described the prominent role of the prefrontal cortex in tasks requiring AR (e.g., Christoff *et al*., 2001; Green, Fugelsang, Kraemer, Shamosh, & Dunbar, 2006; Wharton *et al.,* 2000).

3.6 ASPECTS OF ANALOGIES AND THEIR INFLUENCE ON CHILDREN'S PERFORMANCES

According to several authors, the material used in the analogies tends to influence children's ability to solve the tasks, such as the number of relations involved or the type of relations used.

3.6.1 Number of relations

Several researchers found that when the complexity[4] level increased, which meant when participants had to consider more and more relations, the success rate decreased (Halford & McCredden, 1998; Halford, Wilson, & Phillips, 1998; Mulholland, Pellegrino, & Glaser, 1980; Pellegrino & Glaser, 1979; Scharnhorst & Büchel, 1995). Vodegel Matzen, Van der Molen, and Dudink (1994) found that the number of relations accounted for 47% of the variance in item complexity, which was comparable with the 45% found by Carpenter *et al.* (1990). Together with the relation type they accounted for 63% of the variance. Furthermore, the type of relation and the working memory requirements are known to be highly correlated with the item complexity (Pellegrino & Glaser, 1979), at least in typically populations. Within the test complexity, the number of the possibilities of answer and the relations involved between the *A*, *B* and *C* terms of the analogy increases. In other words, the more information that needs to be memorized, the more the memory is overloaded, which induces a risk of losing part of the information (Carpenter *et al.*, 1990; Pellegrino & Glaser, 1980).

In addition, other authors showed that time increased according to the number of elements in the analogies (e.g., Arendasy & Sommer, 2005; Bethell-Fox, Lohman, & Snow, 1984; Foorman *et al*., 1985; Sternberg, 1977b). Mulholland *et al*. (1980) observed that the increase of elements and transformations led to the increase of processing time needed to solve the analogies. In their words, "as both elements and transformations increase, then a solution may require substantial external memory that is unavailable, thus creating a need for alternative processing strategies that are time consuming with respect to item solution" (p.265). The authors also discovered that the most difficult items were also those composed of multiple transformations. When there was an increase of the number of elements, there was an increase of error rates (Holzman, Pellegrino, & Glaser, 1982). Bethell-Fox *et al.* (1984) used the same analogies and found similar results.

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[4] In this dissertation, we assume that "item complexity" equals the number of elements that one has to consider in order to solve the items; as Primi (2001) stated: "The number of elements refers to the number of geometric figures or attributes in an existing matrix problem" (p.45). Whereas "item difficulty" represents the types of relations, such as familiar *vs.* unfamiliar, conceptual *vs.* perceptual relations.

3.6.2 Types of relations

3.6.2.1 Perceptual vs. Conceptual relations

According to some researchers (e.g., Alexander, White, Haensly *et al*., 1987; Büchel, 2006; Klein & Stafford, 1978; Lifshitz, Tzuriel, & Weiss, 2005; Piaget *et al*., 1977), a distinction can be made between conceptual and perceptual relations in analogical tasks. According to Piaget *et al.* (1977) and to Klein & Stafford (1978), perceptual analogies were more complex than conceptual ones, because perceptual analogies were based on visual-perceptual relations, which required the consideration of 2 characteristics (for instance color and shape), whereas conceptual analogies were based on abstract semantic relations, which required only the consideration of a single characteristic. Based on the work of these authors, it seemed that young children encounterd more difficulties with perceptual relations than with conceptual ones.

Other authors reported opposite results. Carpenter *et al.* (1990), for example, concluded that individuals first considered simple rules before complex ones. That meant that when confronted with analogical items, they would solve them by relying on simple relationships, which were the search of perceptual similarities, before relying on more complex relationships, which represented the search of conceptual similarities.

Tzuriel and Galinka (2000) asserted that conceptual analogies required higher-level processes but perceptual analogies did not. According to them, perceptual analogies entailed relations that were immediately visible, whereas conceptual analogies required an abstraction of relations, which required a more difficult process. They created the *Children's Conceptual and Perceptual Analogical Modifiability* test (CCPAM), a dynamic assessment procedure, in order to investigate the effects of perceptual and conceptual analogies (this test will be further described in Chapter 5). Tzuriel's results (2007; Tzuriel & Galinka, 2000) contradicted Piaget, Klein and Stafford's assertions.

Gentner (Gentner & Markman, 1997; Medin, Goldstone, & Gentner, 1993) discovered that individuals determined the perceptual similarity of images with the same processes used in conceptual analogies. In addition, Gentner (Gentner, 1977, 1988, 1989, 2003; Gentner & Ratterman, 1991; Gentner, Rattermann, Markman, & Kotovsky, 1995; Ratterman & Gentner, 1998) found that perceptual similarity was often correlated with conceptual similarity, and that a developmental progression existed from perceptual characteristics to conceptual characteristics. In other words, young children tended to consider only perceptual characteristics and with the increase of age they also considered conceptual characteristics.

3.6.2.2 Color as a predominant relation

Several studies have shown that items requiring attention to less salient relation, such as orientation, were more difficult to solve than items requiring attention to salient relations, such as size and shape (Odom, Astor, & Cunnigham, 1975; Siegler & Svetina, 2002). The predominance of color as the most successful relation was consistent with former studies (e.g., Pick & Pick, 1970; Zeaman & House, 1963).

Siegler and Svetina (2002) presented analogical items to 6 to 8 year-old children. The items were composed of 4 relations: color, size, shape and orientation, given across 7 sessions. Results showed that in session 1, answers were more often correct with the color and the shape relations (83% and 87% respectively) than with orientation and size relations (72% and 77% respectively), whereas in session 7, answers were correct in the same manner on all 4 relations.

Alexander, Willson, White, and Fuqua (1987) presented geometric blocks varying in 3 dimensions: size, shape, and color. Analyses have shown that the most successful relation was color, followed by shape, and finally size. Tzuriel and Klein (1987) found the same results for color, but those of size and shape were the opposite. According to Tzuriel and Klein (1987), size perception developed later in age and shape was the most difficult relation to acquire, hence “more emphasis should be given to shape perception in teaching analogies than size and color” (p.285).

3.7 SUMMARY

This chapter set out to examine the definition of analogy and the ways to measure AR. We exposed the AR ability in young and older children. We considered studies that supported Piaget’s developmental theory, and others that brought strong evidence against the hypothesis that reasoning about higher-order relations was a developmental skill that emerged only in adolescent life.

AR in young children is not absent, but rather incomplete, because they do not infer all possible relations between the terms. Singer-Freeman (2005) suggested several aspects which prevent AR in young children but not in older children. One of these aspects is the inability to infer the relation between the *A*-*B* terms. If this relation is not inferred, young children would not be able to apply this relation between the *C*-*D* terms. A second aspect is a lack of relational knowledge about the relations involved, which prevent them from finding the correct solution.

Through the exposed studies, we highlighted that young children's performances presented inferior strategies, such as associative reasoning, sometimes because they did not understand what they had to do in the analogical tasks, and sometimes because these tasks exceeded their mental resources. Sometimes, the amount of information went beyond the children's working memory capacity (see Chapter 6), which led young children to poor performances. In order to avoid this memory overload, analogies could propose external memories, which will be highlighted with the description of the CAM test (see Chapter 7).

Young children are not the only ones to obtain low performances in analogical tasks. We assume that their performances in AR will, at least partially, mimic those of the students with intellectual disability participating in our study. In the next chapter, we will describe AR ability in this second population.

4. INTELLIGENCE AND ITS INDIVIDUAL DIFFERENCES

4.1 INTRODUCTION

Since our research population is composed of individuals with intellectual disability (ID), this chapter focuses on intelligence in relation to ID. We will not expose different definitions of intelligence as proposed by Gardner, Cattell & Horn, Guilford, Thurstone, Sternberg, and many others. Our interest lies in the cognitive abilities of an atypical group: individuals who deviate with regard to standards of intelligence.

We also will describe the origin of ID, that is to say the debate between developmental and difference theories. Finally, we will examine the reasoning abilities of people with ID and particularly their AR abilities.

4.2 DEFINING INTELLIGENCE

Studying ID is a promising way to study intelligence (Detterman, Gabriel, & Ruthsatz, 2000). Intelligence can be seen as “a general mental ability. It includes reasoning, planning, solving problems, thinking abstractly, comprehending complex ideas, learning quickly, and learning from experience” (Luckasson *et al.*, 2010, p.15). It is also defined as the ability to adapt oneself adequately to new situations or the capacity to acquire capacity (Sternberg, 2000).

Intelligence is usually evaluated using a measure of IQ, which is distributed on a Gaussian curve, with a mean of 100 points and a standard deviation of 15 points (Grossman, 1973). According to the 11th edition of the AAIDD manual (2011), a diagnostic of ID can be settled “through the use of standardized measures normed on the general population, including individuals with and without disabilities (Luckasson *et al*. 2010, p.43). A diagnostic of ID means that there is a deviation from “normal” human functioning capacity in comparison with typically developing individuals. Approximately 70% of the population is located at $\pm$ 1 standard deviation from the mean ($85 \leq M \leq 115$) on the normal curve. Approximately 15% are located on both sides of the boundaries (between 70 and 85, and between 115 and 130). Only 4% are located over or under 2 standard deviation from the mean (> 130 = exceptionally gifted persons; < 70 = ID).

4.3 DEFINING INTELLECTUAL DISABILITY

4.3.1 Change of terms: "mental retardation" becomes "intellectual disability"

Mental retardation and ID are synonyms. The term "intellectual disability" is official only since January 2007, as the American Association on Mental Retardation (AAMR) changed its name to the American Association on Intellectual and Developmental Disabilities (AAIDD). Both terms emphasized the same definition but the modification of the words highlighted a change of vision. However, the term of ID presented in the 11th edition of the AAIDD (2010) manual was preferred to the term mental retardation, because the latter reflected a gap between the mental age and the chronological age of an individual (Wehmeyer *et al*., 2008), and the former

> (a) better reflects the changed construct of disability […], (b) aligns better with current professional practices that focus on functional behaviors and contextual factors, (c) provides a logical basis for understanding supports provision due to its basis in a social-ecological framework, (d) is less offensive to persons with disabilities, and (e) is more consistent with international terminology. (Luckasson, *et al*., 2010, p.3)

The 11th edition is a result of decades of work about the definition of ID. It is a work reflecting the evolution of the ID construct, the change of the definition structure between ID and mental retardation, and the consideration taken to improve the lives of individuals who have an intellectual functioning different from others. Many studies that we will mention in this chapter used the previous term "mental retardation". Hence, we will use both terms as equivalent, ID referring to studies after 2007 and "mental retardation" to those before 2007.

4.3.2 Former and current definitions of intellectual disability

The AAMR proposed several definitions of mental retardation during past decades. They highlighted a failure of social adaptation of individuals to their environment; impairments in maturation, learning and social judgment; the presence of the ID before 18 years old; or the importance of social and environmental factors. All these elements are still present in the last definition of the AAIDD (2011). To sustain this new definition, 4 approaches were used to define the construct of ID: social, clinical, intellectual, and dual-criterion. The social approach states that individuals are defined as having ID because their behavior is not adapted to their environment. The clinical approach mentions that the definition of ID refers to a syndrome that is clinically established. The intellectual approach highlights that an individual's intellectual functioning needs to be measured with an IQ test and thus be reflected by an IQ score. Finally, the dual-criterion approach refers to intellectual functioning and adaptive behavior at the same time (Luckasson, *et al.*, 2010).

According to the 11th edition of the AAIDD manual, the current definition of ID is the following: "Intellectual disability is characterized by significant limitations both in intellectual functioning and in adaptive behavior as expressed in conceptual, social, and practical adaptive skills. This disability originates before age 18" (Luckasson, *et al.*, 2010, p.6).

The AAMR was not the only association that defined the term of mental retardation. The Diagnostic and Statistical Manual (DSM; DSM-IV-TR, 2003), collaborating with the American Psychiatric Association (APA, 2000), mentioned characteristics that were similar with the AAMR/AAIDD definition, such as a sub-average intellectual functioning appearing during the developmental period, deficits in adaptive behavior, and the existence of symptoms before age 18. However, a major distinction consisted in the 4 labels describing the mental retardation levels: mild, moderate, severe and profound. These labels were based on standard deviation ranges below the IQ average mean 100. Although the AAMR also proposed these 4 levels in the past, they no longer existed in the 11th edition.

Concerning this dissertation, we will refer at both AAIDD (2011) and DSM-IV-TR (2003) definitions. One part of our population is composed of students with ID. We selected participants with a moderate ID, even if the term "moderate" does no longer exist in the 11th edition of the AAIDD. However, as this study follows 2 previous studies (i.e., Büchel *et al*., 1997; Angeretas & Gonzalez, 2002) which selected participants with moderate ID, we decided to use the same terms in order to keep a consistency between the studies.

4.4 ORIGIN OF INTELLECTUAL DISABILITY: THE DEVELOPMENTAL-DIFFERENCE CONTROVERSY

There is evidence that when children become older, they are capable of performing more difficult tasks than when they were younger. Developmental tests can measure some of these differences between children and it is generally assumed that mental age reflects a measure of an individual's cognitive developmental level (Ellis & Cavalier, 1982). However, children with ID do not perform as well as children without ID. Two theories attempted to explain the origin of ID. The well-known controversy opposing the developmental theory to the difference (or defect) theory is still current and concerns the importance of mental age opposed to IQ.

Shortly described, the developmental theory asserts that when children are matched on mental age, their scores and performances are similar, whereas the difference theory asserts that children with mental retardation have lower performances compared to typically developing children of the same mental age (Baumeister, 1994). In contrast, the developmental theory is focused on the acquisition of essential concepts, such as number, categorization, and spatial relations. As for the difference theory, its main interest is to compensate the postulated deficit processes by way of the acquisition of cognitive strategies (Büchel & Paour, 2005).

4.4.1 Difference or Defect theory

The difference position emerged because some researchers desired to explain the difficulties associated with low intelligence (Hasselhorn, 1998). The works of Lewin (1936) and Kounin (1941) have shown that children with mental retardation "were suffering from a defect relating to a more rigid style of problem solving" (Hodapp & Zigler, 1997, p.117). Kounin postulated that individuals with mental retardation had more rigid brain cognitive regions than typically developing individuals of the same chronological age (Zigler & Balla, 1982a, 1982b).

Other researchers found some defects explaining lower cognitive performances of individuals, such as short-term memory deficit (Ellis, 1978), weak organizational processes (Spitz, 1966), deficit in attention (Zeaman & House, 1984), ineffectiveness in using strategies (e.g., Bray, Huffman, & Grupe, 1998; Bray, Saarnio, Borges, & Hawk, 1994; Brown, Bransford, Ferrara, & Campione, 1983); and deficit in executive processes (Belmont & Butterfield, 1971).

The disadvantage of the defect approach was "its isolated focus on the cognitive limitations of individuals with mental retardation" (Hasselhorn, 1998, p.3). This focus on "identifying deficits [...] overlooks the fact that mental retardation is not only associated with cognitive deficits but also with a large quantity of cognitive competencies" (p.3). Some researchers were so prone to find deficient processes that the term “deficit hunting” was used (Borkowski & Cavanaugh, 1979). In the same idea, the “everything deficit” was mentioned because individuals with mental retardation obtained lower performances than typically developing individuals on the majority of cognitive tasks (Detterman, 1979; Hulme & Mackenzie, 1992).

Other researchers revealed that results of the above-mentioned studies have to be interpreted with caution because some studies were located in artificial places like laboratories. Furthermore, many of the tasks used were not suitable for individuals with mental retardation (e.g., Bray *et al*., 1998; Büchel & Paour, 2005).

4.4.2 Developmental theory

Zigler (1969) reacted against defect theories because of the multiple deficits. With his colleagues, he carefully examined “the conditions under which children with retardation behaved more rigidly” (Hodapp & Zigler, 1997, p.117). They found that some children with ID suffered from social and emotional deprivation (Zigler, Hodgden, & Stevenson, 1958) experienced in their institutions or in their family. These negative experiences influenced skills acquisition and led to poor performances (Milgram, 1982). According to Zigler (1969), motivational factors such as “fear of failure and insecurity toward approaching new situations” (Dulaney & Ellis, 1997, p.180) represented the first cause for rigidity of behavior in individuals with mental retardation.

In other words, according to Zigler, children with ID (QI > 50) went through the same Piagetian stages of cognitive development as typically developing children (Hasselhorn, 1998; Hodapp, Burack, & Zigler, 1998; Hodapp & Zigler, 1997; Weisz & Zigler, 1979) but they were “presumed to develop cognitively at a slower rate and reach a lower final level of development” (Ellis & Cavalier, 1982, p.125; see also Meador & Ellis, 1987). Therefore, children with ID and typically developing children having the same mental age, but different chronological age, should obtain the same scores when assessed on different types of tasks. They may show differences in motivation for example, but should get identical scores on cognitive tasks (Ellis & Cavalier, 1982). They were similar in their cognitive processes and performance and thus, there should be no differences associated with IQ (Baumeister, 1994; Bennett-Gates & Zigler, 1998; Hodapp & Zigler, 1997; Weisz, Yeates, & Zigler, 1982; Zigler & Balla, 1982a).

4.4.3 Solving the debate

Several researchers attempted to solve the developmental-difference debate. Detterman (1998) proposed a systemic theory of intelligence that also explained ID. According to his theory, intelligence possesses the properties of a complex system and the characteristics of intelligence can be understood from a general perspective of the system. Detterman assumed that the difference theory and the defect theory were not so discordant with each other. He proposed that these theories referred simply to different aspects of the above-mentioned general perspective. Therefore, ID was the consequence of one or several deficits, which deteriorated the general system.

Paour (2004) proposed an integrative conception of mental retardation. According to him, mental retardation is the result of interactions between 3 major components. The first component is a limitation of the basic capacities of information treatment. Individuals with mental retardation show deficits in the speed, quality or quantity of information treatment. The second component is a chronic cognitive low-functioning. Individuals with mental retardation are less able to efficiently mobilize their cognitive potential. Finally, the third component is the developmental consequences of the 2 previous components, such as delay, incompletion, tardiness, and cessation.

Weisz and Yeates (1981) reviewed approximately a hundred studies comparing participants with and without mental retardation matched on mental age on Piagetian tasks. Among these studies, only 24% corroborated the difference position by highlighting that the highest performances were obtained by persons without mental retardation, whereas 72% of the studies sustained the developmental position with no differences between the participants. The remaining 4% concerned a third position that was not relevant for our research. However, Weiss, Weisz, and Bromfield (1986) reviewed the performance of individuals with and without mental retardation in information-processing tasks and found results that supported the difference position.

All these studies highlighted the controversy between the developmental theory and the difference theory, which is still current. However, in this doctoral dissertation, both theories will be followed in order to explain the potential differences in performances.

4.5 DEFICIT COGNITIVE FUNCTIONS OF INDIVIDUALS WITH INTELLECTUAL DISABILITY IN ANALOGICAL REASONING

As said in the previous chapter, individuals with ID tend to demonstrate poor skills compared with typically developing individuals in a variety of areas but especially in AR. For example, they encounter difficulties during the encoding process (i.e., one of the processes that is necessary to reason by analogy), as they spend less time to explore the information than typically developing individuals (e.g., McConaghy & Kirby, 1987; Sternberg, 1977a). Moreover, they often treat the information superficially by focusing directly on the elements of answer and not on the matrix (e.g., Büchel, 1993; Dulaney & Ellis, 1997; Paour, 1992, 1995).

In addition, individuals with ID lack comparative behavior, which hampers them from comparing the elements in terms of similarities and differences (Schlatter, Büchel, & Thomas, 1997). Feuerstein (1980) considered comparative behavior to be one of the most important cognitive processes because it comprised integration, organization of relations, and inference, which all together are components for abstract thinking. By using comparative behavior, individuals are able to detect relationships between objects and to reason by analogy (Klauer, 1999).

At the same time, individuals with ID possess but do not use strategies for solving the tasks (Brown, 1974; Borkowski & Büchel, 1983) because teachers or support workers rarely teach those skills, since it is commonly believed that they are unable to solve abstract cognitive tasks (Agran & Wehmeyer, 2005; Robinson, Zigler, & Gallagher, 2000). Moreover, these individuals are said to be inflexible when confronted to problem-solving situations, as they do not adapt their actions to new tasks or situations and tend to repeat previous strategies even if they are not suitable for the task they are confronted with (Agran & Wehmeyer, 2005).

Individuals with ID also present deficits in their memory[5]. They have a weaker working memory in comparison to typically developing persons and do not organize the information in their long-term memory as well as these persons (Alloway, Gathercole, Kirkwood, & Elliott, 2009; Numminen, Service, & Ruoppila, 2002; Reed, 1996). Moreover, they tend to focus on irrelevant aspects of the task, which overload their working memory (e.g., Reed, 1996; Zeaman & House, 1979). Once they have discovered one or several

[5] The information related to memory will be more described in Chapter 6.

relations, it becomes difficult for them to maintain these relations and to treat others at the same time, as their memory span is lower than typically developing individuals, and because they do not use the rehearsal strategy (e.g., Hasselhorn, 1998; Hulme & Mackenzie, 1992), which lead them to lose part of information (Russell, Jarrold, & Henry, 1996). In addition, Büchel and his collaborators (Büchel & Schlatter, 1997; Büchel *et al.*, 1996, 1997; Schlatter, 1999; Schlatter & Büchel, 2000) demonstrated that individuals with moderate ID were able to treat 2 relations but not 3, as their memory capacities were overloaded.

Besides deficit cognitive functions, individuals with ID tend to demonstrate a deficit of attention (Hulme & Mackenzie, 1992; Tomporowski & Tinsley, 1997) and a low motivation compared with typically developing individuals (Büchel, 2007; Paour & Bailleux, 2005). Motivational and affective factors can decrease the cognitive processes that are required to solve a task and influence negatively the attitudes of persons with ID (Feuerstein, 1980; Tassé, Morin, & Aunos, 2003). Their general involvement in cognitive tasks can hence be affected and thus, their performances can be impaired. Zigler and his colleagues (Hodapp & Zigler, 1997; Hodapp *et al.*, 1998; Zigler & Burack, 1989) recognized the importance of motivational factors characterizing an individual’s personality structure. Because of their lower cognitive structures, individuals with ID are often confronted with failure and negative experiences and need to be presented with attractive tasks (e.g., Agran & Wehmeyer, 2005; Balla & Zigler, 1979; Hodapp, Burack, & Zigler, 1990; Merighi, Edison, & Zigler, 1990; Siegler, 1979; Switzky, 1997; Zigler & Balla, 1981, 1982a; Zigler & Hodapp, 1991).

4.6 SUMMARY

This chapter reviewed the recent definitions of the ID concept, as well as the differences between individuals with ID and typically developing children. We saw that persons with ID were characterized by deficit cognitive functions, especially in the area of AR. We also mentioned that these persons tended to demonstrate slower reaction times compared with typically developing children. In other words, the lower IQ was, the slower the speed was for information processing (Hulme & Mackenzie, 1992; Jensen, Schafer, & Crinella, 1981). The same was true for typically developing children: the younger the children were, the more time was needed to solve problems, compared with older children (Foorman *et al*., 1985).

These limitations and the pervasive belief that these individuals could not go beyond a concrete level of reasoning may prevent support workers, professionals and psychologists to propose abstract cognitive problems to individuals with ID (Hayes & Taplin, 1993; Lifshitz, Weiss, Tzuriel, & Tzemach, 2011).

As we exposed it, the individual's level of intelligence is generally assessed by static tests (or IQ tests), which represent a major tool in classifying and defining individuals, and in measuring intellectual functioning, as stated by the AAIDD (2011). Intellectual functioning of individuals can also be assessed by learning tests. In the next chapter, we will present the advantages and disadvantages of static tests and learning tests.

5. DYNAMIC ASSESSMENT OF ANALOGICAL REASONING IN INDIVIDUALS WITH INTELLECTUAL DISABILITY

5.1 INTRODUCTION

In this chapter, we will begin by examining two ways for measuring intelligence, that is to say static tests and learning tests. We will expose the advantages and disadvantages of both test types. Then, we will describe the dynamic assessment procedure for individuals with ID.

Finally, we will examine 2 AR tests for persons with ID: the *Children's Conceptual and Perceptual Analogical Modifiability Test (CCPAM)* and the *Analogical Reasoning Learning Test (ARLT).*

5.2 ASSESSING INTELLIGENCE

In order to measure intelligence, either static tests (also called IQ tests or intelligence tests) or learning tests can be administered to make an estimation of the relative position of the test outcome of a person compared with those of others.

5.2.1 Advantages and disadvantages of static tests

Static tests possess several psychometric qualities, the value of such is recognized by most researchers. Among them we can find the objectivity, reliability, and validity (Anastasi, 1988). Although various characteristics of static tests are important, this is not the main interest in this dissertation, hence, we will expose only the main characteristics of static tests and of learning tests as well.

Static tests measure a person's actual level of performances and its acquired knowledge and skills at one moment of time. Even when scores reflect mental age, they do not give a precise picture of the intellectual functioning and do not give any indication of the learning ability (Chen & Siegler, 2000). Besides, they give little or no information about corrective action. They tend to ignore social and practical skills which represent important aspects of intellectual functioning (Luckasson *et al*., 2010) as well as the influence of factors such as motivation, anxiety, self confidence, locus of control and so on, which become very consequential for the task completion (Haywood & Switzky, 1986; Tzuriel, 2001).

Test scores are normed on the general population and are based on the assumption that all persons are exposed to the same learning opportunities (Tzuriel, 2001), and hence produce a reliable score by demonstrating how much a person deviated from the mean (Luckasson *et al*., 2010). Static tests are not suitable for special populations comprising individuals with ID, children of ethnic minority or low socio-economic backgrounds, or children with learning disabilities (Bosma & Resing, 2006; Guthke & Beckmann, 2000) because they cannot estimate the performances of persons within these populations precisely enough (Haywood, 1997; Lidz, 1991; Reschly, Myers, & Hartel, 2002; Tzuriel & Haywood, 1992). Expressly, individuals with ID or young children do not always understand the task demands and because mediation or verbal exchanges between them and the experimenters are not allowed during the task, they cannot always perform the task. In order to correct this defect, Willner, Bailey, Parry, & Dymond (2010) proposed to “adapt tests developed and validated for more able people, sometimes using children’s versions of adult tests, or to develop new tests that are specifically designed to be more accessible” (p.367).

5.2.2 Advantages and disadvantages of learning tests

All these dissatisfactions with static tests lead researchers to use another way to assess individual’s cognitive performances. The alternative was to use learning tests or learning potential tests. These tests follow a dynamic assessment procedure, which is “an active teaching process involving an individual’s perception, learning, thinking, and problem solving” (Lifshitz *et al*., 2011, p.327; see also Tzuriel 2001; Tzuriel & Flor-Maduel, 2010). The main interest of the dynamic assessment procedure is not to measure the different deficits but to locate the individuals’ learning potential (Beckmann, 2006; Grigorenko & Sternberg, 1998; Kozulin, 2010; Resing, 2006).

Learning tests – either short or long in duration - integrate one or several training phases that are interactive between the participant and the experimenter, in contrast to static tests. Individuals can receive a simple feedback, isolated and standardized hints, or a complete instruction necessary to solve the task (Guthke, 1990). The number of hints varies from test to test; sometimes they consist in individualized mediation (Tzuriel, 2000), sometimes they are adapted to individuals, and sometimes they are hierarchical (from general to specific).

The learning tests reveal inter-individual differences that can express potential learning capacities. There are preferred to static tests because they promote the process of learning and not only the obtaining of the results (Schlatter & Büchel, 2000). Vygotsky (1978) proposed the term of “zone of proximal development”, which corresponds to the results that an individual can reach with the help of the adult.

Nevertheless, the main criticism of the learning tests was that they generally presented a lack of standardization, which is necessary to assess an individual’s cognitive functioning (Grossman, 1973). The standardization allows comparing individuals in equal conditions (same instructions, same procedure, same conditions, etc.), hence none of the participants are favored in comparison to the others. Nowadays, however, a number of dynamic tests with good standardized instructions have been constructed (see for an overview Lidz & Elliott, 2000; Sternberg & Grigorenko, 2002; Wiedl, 2003).

Several studies have demonstrated that dynamic assessment could deliver very useful information about persons within special populations, such as individuals with ID, with low socio-economic background or with learning disabilities. Part of these individuals obtained good performances and even maintained these several weeks after the training session (e.g., Büchel, 1995; Budoff, 1987; Carlson & Wiedl, 1978, 1992; Grigorenko & Sternberg, 1998; Jepsen, 2000; Resing, 1997; Tzuriel & Klein, 1985). Therefore, dynamic assessment procedure allows educators to get a more accurate estimation of the level of intelligence of individuals with ID, and to give predictive value for future performances (Tzuriel & George, 2009; Tzuriel & Klein, 1985).

5.3 DYNAMIC ASSESSMENT TOOLS MEASURING ANALOGICAL REASONING IN INDIVIDUALS WITH INTELLECTUAL DISABILITY

5.3.1 The Children’s Conceptual and Perceptual Analogical Modifiability Test (CCPAM)

Tzuriel and Galinka (2000), Vakil, Lifshitz, Tzuriel, Weiss, and Arzuoan (2010), and Lifshitz *et al.* (2011) used the *Children’s Conceptual and Perceptual Analogical Modifiability* test (CCPAM), a dynamic assessment tool composed of classical analogies in the *A:B::C:D* form, with children, adolescents and adults with mild and moderate ID. The conceptual subtest consisted of 3 types of relations: “functional” (ex. “lives in”); “part-whole”, and "categorical". An example of a conceptual analogy is *dog:bone::girl:sandwich*, with the relationship being: "eat". The perceptual subtest consisted of several relation types: "difference" (i.e., position, number, change of color or type of object); "existence" type (i.e., the appearance or disappearance of objects); and "opposite" (i.e., object location like on/under).

In the 3 studies, a tailored dynamic assessment procedure was used, which included 5 stages: pre-teaching test, mapping difficulty stage, mediation stage, analyze of the components by the participants, and a post-teaching test. Results showed that both groups improved their scores between the pre-test and the post-test, but the scores were higher for the group receiving the tailored dynamic assessment procedure. The authors explained these results by asserting that the mediation, in the tailored dynamic assessment procedure, was adapted to each individual according to its answers in the mapping difficulty stage. The authors concluded that a good mediation, especially in the encoding and inference processes, allowed better performances in AR in individuals with ID.

5.3.2 The Analogical Reasoning Learning Test (ARLT)

By taking into account all the criticisms made against learning tests, in particular the lack of standardization, as well as the problems encountered by individuals with moderate ID in analogical tasks, in particular a lower memory span and a difficulty to understand the task instructions, Büchel and his collaborators designed the Analogical Reasoning Learning Test (ARLT; Büchel, Schlatter, & Scharnhorst, 1996, 1997; Büchel, 1999b; Büchel & Schlatter, 1997, 2001; Schlatter, 1999; Schlatter & Büchel, 2000; Hessels-Schlatter, 2002). This test, comprising a dynamic and standardized assessment procedure for adolescents with moderate to severe ID, was designed to evaluate their learning potential in analogical tasks. The test scores showed high reliability (α Cronbach: .88; test-retest stability: .83) and a good predictive validity (Schlatter, 1999).

Three phases composed the ARLT: first, the preparatory phase allowed the students to be familiarized with the material and task orders; the second phase, the learning phase, entailed mediation and gave hints to the participants, which were standardized and followed a hierarchy (from general to specific); finally, in the post-test phase, the participants had to solve maintenance, near transfer and far transfer tasks without mediation. Participants received 2 points if they were successful on the first trial, 1 point if they were successful after receiving help, and 0 points if they still failed after help. These different scores allowed the participants to graduate into 3 groups: the “gainers” (according to Budoff’s categorization, 1987), those who profited from training and had a high learning potential, the “undetermined”, and the “non-gainers”, those who did not profit from training and had a low learning potential.

The authors were very careful to establish standardized and hierarchical hints. They adopted Wood, Bruner and Ross’s (1976) principle of scaffolding, which helped learners to understand what they could not understand by themselves. They also adopted Vygotsky’s (1978) principles to follow the mediation. For that reason, the hints were specific to the participant’s answer, either precise, which meant targeted on one relation, or general, leading the participant to explore more of the matrix. Participants were gradually encouraged to proceed with autonomy and to need fewer and fewer hints.

The ARLT has been composed of nineteen 2×2 analogical matrices presented on wooden blocks. Items were displayed in a figurative concrete and geometric modality with 2 levels of complexity. The experimenter presented the *A*, *B* and *C* elements and asked the participant to find the *D* term among 6 possibilities in level 1 and among 8 possibilities in level 2, with only one being correct in both levels as shown in Figure 5.1. Participants had to infer 2 relations in level 1, that being 1 between the *A*-*B* terms and 1 between the *A*-*C* terms. In level 2, they had to infer 3 relations, which meant to find 2 relations between the *A*-*B* terms and 1 between the *A*-*C* terms. Relations involved in the analogies varied in color, size, shape, orientation, addition and number. With this material, the participants could actively manipulate the elements of the answer, they could observe what they were doing and hence could better understand the task.

Figure 5.1 “Ice-cream” item (1st level of complexity) and “Leaf” item (2nd level of complexity; Schlatter, 1999)

The test was administered to fifty-eight adolescents with moderate to severe ID (*M* chronological age [CA] = 13.11). Basically, results showed that two thirds were able to solve the matrices of level 1, but not the matrices of level 2. These individuals were able to maintain the second and the third attributes in memory but probably had already forgotten the first attribute, even if they had decoded this attribute before (Büchel, 2006).

In order to estimate the predictive validity of the ARLT, the participants were divided into an experimental group (EG) or a control group (CG). The EG received a one-month training (classification items, comparison items, analogies items), which was not the case for the CG. Then, a post-test was administered for all the participants, comprising the same kinds of items than in the training. The training was supposed to allow the EG to get better performances than the CG. The results showed that the non-gainers of the EG got similar performances than the non-gainers of the CG, which meant that the non-gainers showed no improvement after one-month training. The same results were found for the gainers of the EG, who got similar performances than the gainers of the CG. Basically, such results were explained by the fact that there was a too short duration of the training (Schlatter, 1999).

5.4 SUMMARY

This chapter set out to examine the advantages and disadvantages of static tests and learning tests. Theorists and professionals more and more agree that static tests do not give a picture of the cognitive intellectual potential of individuals, particularly for those with ID. What is more, they do not provide in prescriptive diagnostic information neither on deficiencies, nor on the manner to help these persons to develop their analogical competencies, nor on suitable types of interventions that would help further their progress (e.g., Lidz & Elliott, 2000; Resing, 2000). As a result, individuals with ID usually show floor effects, and their competences are underestimated. However, static procedures still remain the favorite assessment tools, notably because they are easy to apply (Sternberg, 1985). On the other hand, dynamic procedures have proved their effectiveness, certainly among individuals with ID (e.g., Guthke & Beckmann, 2000; Hessels-Schlatter, 2002; Schlatter, 1999; Schlatter & Büchel, 2000). For atypical individuals in particular, dynamic assessment is a good predictor for future cognitive performances (Guthke, Beckmann, & Stein, 1995). According to Guthke and Beckmann (2000), a prognosis has to be based on outcomes of both learning tests and static tests, which lead “to a better diagnostic foundation for determination of interventions for the individual child” (p.19).

Recent studies in dynamic assessment proved that they can be considered to be a good tool for measuring performances of participants involved in special education by allowing them to make individually different progress in problem solving, and to acquire strategies, as it was demonstrated by the *Analogical Reasoning Learning Test (ARLT)*. Individuals with ID are able to learn skills and take advantage of training, in opposition to what too many researchers think about them (Resing, 2000). However, despite all the advantages of training, individuals with ID still tend to get lower performances in comparison to those acquired by individuals of the same mental age. One possible explanation lies in potential restrictions in their memory capacity, with a shorter memory span and problems of memorization. The inability to process several relations in analogies may, for example, be due to limits in individual’s working memory (Halford, 1993), a theme that will be discussed in the next chapter. Furthermore, in Schlatter’s (1999) study, the majority of participants were able to infer 2 relations but not 3. In order to explain these results, a memory overload was postulated. A previous study case (Diez, 1994) already indicated that most of the participants with moderate ID had a tendency to use the last decoded attributes in analogies and not the first ones. On forehand, it seemed that the limited memory span of the participants might have prevented them from memorizing all the relations and from solving matrices of the highest level of complexity (Büchel, 2006).

6. MEMORY

6.1 INTRODUCTION

Often a person is unable to recollect, at a given moment, but when he searches he can, and he finds what is sought. This occurs when he excites many changes, until he excites a change of a sort on which the thing will follow. (Aristotle, cited in Glidden, 1979, p.619)

This quotation from Aristotle illustrates that the subject of “memory” has been of interest for centuries. In the last century, several memory models were proposed explaining memory function and the processes playing a role. At the same time, correlations between memory performance and intelligence were highlighted, justifying the presence of memory subtests in psychometric tests, such as the K-ABC (Kaufman & Kaufman, 1983) or the WISC-R (Wechsler, 1974).

Although other memory models exist, we will focus, in this chapter, on one of the most well-known models of memory, especially Baddeley and Hitch’s model (1974) revealing the working memory (WM) concept because we are interested in the processes and the cognitive functions and not in the neurological components laying behind these processes. This chapter will continue with a discussion about recent investigations that follow this model. Next we will discuss the WM capacity and the notion of memory span. After that, this chapter will focus on the memory of individuals with ID, since that it is the main population we studied in this thesis, and sub-chapters on strategies, training and external memories are added. The chapter will end with information regarding relations between aspects of WM, intelligence and AR.

6.2 STRUCTURE OF MEMORY

Memory was seen as a unitary store until works of famous researchers such as Waugh and Norman, Atkinson and Shiffrin, and Baddeley changed that opinion. These authors agreed on the fact that memory was composed of several components. Baddeley (1997) proposed several reasons against the unitary view of memory. Among them, he argued that memory appeared to be composed of 2 main components, the short-term and the long-term stores, the capacity of each component being different. Basically, the short-term store had a limited storage capacity, whereas the long-term store had an unlimited capacity.

6.2.1 The modal model

By the late 1960s, Atkinson and Shiffrin (1968) proposed the well-known “modal” model. According to them, the memory structure was composed of 3 different components: the sensory register, the short-term memory (STM), and the long-term memory (LTM). The information coming from the environment was stored first by the sensory register, which could maintain it very briefly. Then the information was encoded and entered the STM, which could hold information and also manipulate it for a few seconds. Information usually decayed after approximately 2 seconds unless it was rehearsed. If that was the case, it was transferred into the LTM, which had an unlimited capacity (Baddeley, 2001, 2007; Ericsson & Kintsch, 1995).

This model has been seen as the best explanation of memory functioning at that time. However, two main issues were raised. First of all, the STM was seen as holding information and transferring it into the LTM. Said differently, “the longer the information was held, the higher the probability of transfer, and the better the learning” (Baddeley, 2007, p.2), but the attempts to test this assumption failed. Secondly, the STM represented an essential stage for the long-term learning process. Consequently, individuals with a short-term deficit would get impaired performances in the LTM, which, subsequently, was not found either (Baddeley, 2007).

6.2.2 Baddeley’s multicomponent model

Following these two issues, Baddeley and Hitch (1974) suggested that the STM described by Atkinson and Shiffrin should be replaced by a WM store composed of 3 components. The multicomponent model, as expressed in Figure 6.1 below, is composed of the central executive, an attentional control system which coordinates 2 slave systems, the phonological loop, and the visuospatial sketchpad.

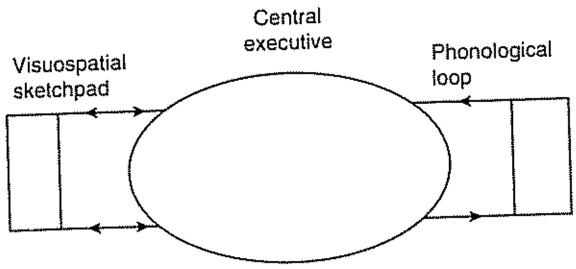

Figure 6.1 Baddeley & Hitch's multicomponent model of WM (Baddeley & Hitch, 1974)

The central executive is responsible of several attention processes, such as focusing, dividing, or switching (Baddeley, 1986). The phonological loop holds verbal information and comprises 2 components, a phonological store and an articulatory rehearsal system. Information in the phonological loop is characterized by 2 types of effect. The similarity effect implies that items that are similar in sound are less well recalled than items that are dissimilar in sound. As for the word length effect, it reflects that longer words are less well recalled than shorter ones (Baddeley, 1986). Concerning the visuospatial sketchpad, it holds visual and spatial information temporarily and represents a connection between verbal and visual information, provided by LTM or the senses (Baddeley, 1986).

Several decades later, Baddeley (2000) proposed a revised model of WM, by adding a fourth component, the episodic buffer (see Figure 6.2), which was assumed to build a connection between the 3 components and the LTM. The episodic buffer represents a temporary storage system "that is able to combine information from the loop, the sketchpad, long-term memory, or indeed from perceptual input, into a coherent episode" (Baddeley, 2007, p.148).

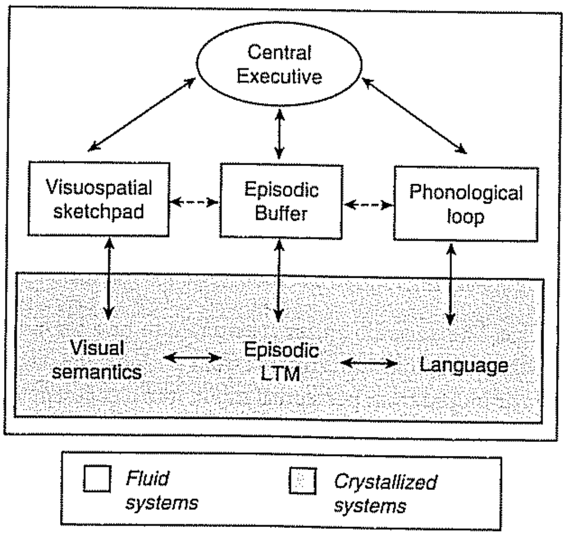

Figure 6.2 Baddeley's revised model of WM (Baddeley, 2000, p.421)

Ericsson and Kintsch (1995) followed Baddeley's work about WM, but proposed a division of WM into 2 components: the long-term WM (LT-WM) and the short-term WM (ST-WM). The information is temporarily stored in the ST-WM and it is maintained longer in the LT-WM. According to the authors, the LT-WM, once acquired, is not a capacity which can be applied generally to complete the ST-WM in cognitive activities. On the contrary, the LT-WM is acquired in particular domains in order to satisfy specific requests imposed by cognitive activities.

Ericsson and Kintsch (1995) asserted that memory performance was due to the use of LT-WM, which was considered as being more efficient than Baddeley's WM. McNamara and colleagues (McNamara & Kintsch, 1996; McNamara & Scott, 2001) corroborated Ericsson and Kintsch's point of view by asserting that usually WM retrievals from LTM require a couple of seconds, whereas LT-WM retrievals require approximately 400 milliseconds.

6.2.3 Challenging Baddeley's model

Baddeley's tripartite model was contested by Cornoldi and his colleagues (Cornoldi, Rigoni, Venneri, & Vecchi, 2000; Cornoldi & Vecchi, 2003), which argued that the model did not give sufficient explanations for deficit performances in children with disabilities. Cornoldi *et al*. proposed a continuity model that described WM deficits according to 2 continuous dimensions: the horizontal and the vertical dimensions. The former suggested that some children had difficulties in tasks presenting visuospatial material, whereas other children encountered difficulties in tasks involving verbal material. The latter dimension reflected the degree of control that was necessary for solving a task. Some tasks required lower level of control (e.g., rehearsal tasks), others a higher level (e.g., dual processing tasks) (Lanfranchi, Jerman, & Vianello, 2009).

In order to prove this assertion, Lanfranchi, Cornoldi, and Vianello (2004) conducted a study with children with Down syndrome. They hypothesized that these children would have lower performances on verbal tasks than typically developing children with the same mental age, and that the control level would show differences between groups with a lower performance for children with Down syndrome. They used verbal and visuospatial WM tasks (the description of these tasks can be found in Chapter 8). In verbal WM tasks, results showed that children with Down syndrome (N = 18; M MA = 5.42) encountered difficulties in higher control tasks and obtained poorer WM performances compared to typically developing children (N = 18; M MA = 5.17). Regarding visuospatial WM tasks, the results showed that children with Down syndrome (N = 22; M MA = 4.5) obtained equal performances as typically developing children (N = 22; M MA = 4.5) in tasks requiring low to medium control (differences being not significant), but lower performances in tasks requiring high control. These results confirmed the hypothesis that the control level showed differences between groups, notably, at a disadvantage for children with Down syndrome. Interestingly, they found that children with Down syndrome had fewer deficits in some visuospatial tasks than in verbal tasks compared to typically developing children, which indicated that their performances depends on the nature of the task, which was already demonstrated by other authors (e.g., Ellis, Woodley Zanthos, & Dulaney, 1989; Jarrold, Baddeley, & Hewes, 1999).

In the same manner, Lanfranchi, Carretti, Spanò, and Cornoldi (2009) investigated memory performances in children and adolescents with Down syndrome (N = 34), which were compared to typically developing children (N = 34; M MA = 4.5). The results showed that participants with Down syndrome got lower performances than typically developing children, suggesting, as the above-mentioned studies, that the WM deficit was not pervasive but rather selective.

Lanfranchi and her colleagues (Lanfranchi, Cornoldi, Drigo, & Vianello, 2009) investigated WM in individuals with Fragile X syndrome having moderate to severe ID. Again, they administered WM tasks. The results showed that individuals with Fragile X syndrome (N = 15) had a deficit in the central executive because they obtained lower performances than typically developing children (*N* = 15, MA = 5.2), whereas the phonological loop and the visuospatial sketchpad were preserved. The authors explained these results in terms of the 2 dimensions proposed by Cornoldi *et al*. (2000, 2003). The difference between the groups "tended to increase in correspondence with increase in the required degree of control (…) assuming that the differences between groups can vary in size depending on the distance along the vertical control" dimension (Lanfranchi *et al.*, 2009, p. 114). Cornoldi's continuity model explained that "a single main variable seems able to explain the main differences that can be observed between individuals with mental retardation and typically developing children" (Lanfranchi *et al*., 2009, p. 115).

6.2.4 Memory capacity

Two main theoretical accounts explained WM capacity. Some researchers, such as Baddeley, asserted that WM was characterized by a domain-general attribute which coordinates 2 independent systems (e.g., Baddeley, 1986; Engle, Kane, & Tuholski, 1999; Kyllonen & Christal, 1990; Turner & Engle, 1989). Other researchers suggested that WM capacity was maintained by separable constructs, which were verbal and visuospatial (e.g., Shah & Miyake, 1996). Shah and Miyake (1996), for example, found that the 2 systems represented independent measures, which meant that one system could not predict performances in the other system, and vice versa. They tested performances on spatial memory span and on reading span tasks and their investigations showed that the spatial memory span predicted spatial ability but not reading comprehension, whereas the reading span predicted the opposite. Alloway, Gathercole, and Pickering (2006) studied these 2 theoretical accounts in children. They also wanted to test the distinction between STM, which consisted in the storage of information, and WM which refered to the simultaneous processing and storage of information.

Alloway *et al*. (2006) used the Automated Working Memory Assessment (AWMA), "a computerized tool for assessing short-term and working memory in children aged 4-11 years" (p. 1700). The AWMA was composed of twelve tasks. The verbal STM was measured with 3 tasks: digit recall, word recall, and non-word recall. The verbal WM was also assessed with 3 tasks: listening recall, counting recall, and backwards digit recall. The visuospatial STM was measured with 3 tasks as well: dot matrix, mazes memory, and block recall. Finally, the visuospatial WM was assessed with 3 tasks: odd-one-out, Mr. X, and spatial span (for detailed description of all tasks, see Alloway *et al*., 2006). Children (*N* = 709) aged between

4.5 and 11.8 participated in their study. The results confirmed that verbal and visuospatial STM tasks were only characterized by the storage of information, whereas the verbal and visuospatial WM measures implied simultaneous processing and storage of information. The results also reflected the supremacy of a domain-general mechanism that drived WM capacity, whereas STM capacity was related to domain-specific aspects. The domain-specific constructs hypothesis was also tested but the correlation between verbal and visuospatial WM was too high with a large amount of variance shared (83%). This meant that “verbal and visuospatial working memory capture more common underlying cognitive skills than verbal and visuospatial short-term memory tasks” (p.1713). Finally, the results also showed that young children needed more executive resources than older children when confronted with visuospatial STM tasks. The findings of this study indicated that WM capacity was characterized by domain-specific components for the storage of information and by a domain-general component for the processing of information; this latter aspect being supported by studies involving children (e.g. Alloway *et al*., 2006; Alloway, Gathercole, Willis, & Adams, 2004; Alloway, Rajendran, & Archibald, 2009).

6.3 WORKING MEMORY SKILLS

WM is known to be useful in everyday life and plays a crucial role in higher cognitive tasks, such as writing, learning, orientation, reading comprehension, arithmetic, and reasoning, especially during childhood (e.g., Alloway, Elliott, & Place, 2010; Alloway, Gathercole, & Elliott, 2010; Baddeley & Hitch, 1974; Baddeley, 1986; Daneman & Carpenter, 1980; Engle & Conway, 1998; Engle *et al*., 1999; Just & Carpenter, 1992; Kyllonen & Christal, 1990). Several studies demonstrated close links between learning measures, academic achievement, and WM (e.g., Gathercole, Lamont, & Alloway, 2006). Shortly defined, WM is “the small amount of information that can be kept accessible of “kept in mind” in the service of ongoing cognitive activity” (Cowan & Alloway, 2009, p.303).

It is now widely recognized that poor WM skills are linked to academic difficulties and to inattentive behavior in school (e.g., Cowan & Alloway, 2008; Gathercole & Alloway, 2008; Gathercole *et al*., 2008; Levin, Thurman, & Kiepert, 2010). Poor WM skills are notably associated to difficulties in planning and organizing information (Alloway *et al.*, 2009), in problem solving tasks (Swanson, Jerman, & Zheng, 2008), and in remembering teachers’ instructions (Engle, Carullo, & Collins, 1991).

According to Elliott, Gathercole, Alloway, Holmes, and Kirkwood (2010), there are at least 2 ways to overcome WM difficulties: training WM and modifying the classroom environment. Training WM has demonstrated good results in typically developing children, but also in students with mild ID (Van der Molen, Van Luit, Van der Molen, Klugkist, & Jongmans, 2010) and in individuals with Down Syndrome (Conners, Rosenquist, Arnett, Moore, & Hume, 2008; Conners, Rosenquist, & Taylor, 2001). Modifying the classroom environment, by helping the children in using strategies and by helping the teachers to understand the nature of WM difficulties, has been shown promising as well. To our knowledge, only Elliott *et al*. (2010) tested this second approach by administering the above-mentioned AWMA to 3189 children between 4 and 9 years old with the aims to bring academic gains and to improve WM. Unfortunately, the results failed to prove these aims. The most important aim of the study was to build a more sensitive educational environment for the children, and not to train WM especially, which may explain the failure of the intervention. The authors insisted on the importance to help teachers to understand the nature of WM difficulties. With this knowledge, they may better give helpful practices to the children.

6.4 ASSESSMENT OF WORKING MEMORY

6.4.1 Dual tasks

WM is traditionally measured with dual tasks that contain both a storage task and a processing task. The storage task is often a STM task in which the participants have to memorize and recall lists, most of the time digits or words lists. The role of the processing task is to occupy the WM capacity (Alloway, 2010; Alloway *et al.,* 2006; McNamara & Scott, 2001).

Daneman and Carpenter (1980), for example, created a WM task in which the participants had to listen to series of 2 to 6 sentences and to recall at the same time the last word of each sentence. Turner and Engle (1989) developed a similar task in which the participants had to solve series of arithmetic operations and to read aloud a word that followed the series.

These dual tasks were often designed for children from 6 year-olds and older. Only a few studies investigated WM measures in children younger than 6 year-olds, because the tasks intended for older children were too difficult for younger ones (Lanfranchi & Vianello, 2008), and because the central executive, the phonological loop and the visuospatial sketchpad appeared to develop not at the same pace, especially not in younger children (Alloway *et al.*, 2006). For instance, Gathercole, Pickering, Ambridge, and Wearing (2004) could only administer phonological loop and visuospatial tasks to 4 and 5 year-olds children, but not central executive tasks.

In order to remedy this issue, Alloway and her colleagues (Alloway *et al.*, 2004; Alloway *et al.*, 2006) created a computerized battery that assessed 4 WM components in children between 4 and 11 year-olds, them being the central executive, the phonological loop, the phonological awareness and the episodic buffer. According to the authors, they created the first existing task measuring the episodic buffer, with 2 separate sentence repetition tasks.

6.4.2 Memory span

6.4.2.1 Definition of memory span

WM has the ability to make “certain ideas more readily accessible to ongoing thinking and actions (e.g., items, words, concepts, visual representations)” (Cowan & Alloway, 2009, p.304) but the space and the time are limited. WM can only treat a limited number of items at the same time and can spend only a limited time for each item. It is recognized that we can remember about 7 items at a time, which include lists of words, letters, or digits. This is called the memory span.

Memory span is characterized by 2 aspects. The primacy effect is that the first items are better recalled because they are more rehearsed than other items. The secondary is the recency effect, when the last items are better recalled than the middle ones because they are the last entering the phonological store (Murdock, 1974; see also Baddeley, 1997). Gathercole (1997) mentioned that items to be recalled depended on several variables, such as the length of series, the familiarity of the items, or the spoken duration of the items.

6.4.2.2 Limits of memory span

According to Miller (1956), the capacity of memory span for a typically developing adult is about 7±2 bits of information. However, if these 7 bits are associated into a single unit, which is called “chunk” (either a word, a digit or a letter), then the number of information able to be stored is bigger (Halford & McCredden, 1998; Spitz, 1979). For instance, “it is difficult to remember a list of 9 random letters, but it is easy when the letters form a much smaller number of meaningful chunks (as in the list IBM-NBC-RCA, representing 3 well-known corporations)” (Cowan & Alloway, 2009, p.305).

Miller’s “magical number 7±2” was contested by several authors. For example, Mandler (1967) reviewed many experiments that suggested that the size of memory span was rather 5±2. Cowan (2001) also reviewed several studies; according to him, Miller’s magical number reflected an estimated capacity limit, “rather than a pure capacity limit” (p.112). He proposed a new memory span capacity with the number 4±1. The major distinction between Miller’s number and Cowan’s number was the concept of chunk, the capacity of which was, according to Cowan, about 4 items for recall. Cowan asserted that the main memory capacity in adults was 3 to 5 chunks, whereas “individual scores appear to range more widely from about 2 up to about 6 chunks” (p.114), demonstrating that it was the attention span that was capacity-limited.

Bachelder (2001) seemed to reconcile Miller’s number and Cowan’s number. He showed that there was no difference between Miller’s 7±2 and Cowan’s 4±1. The former corresponded to a 50% criterion, whereas the latter corresponded to a 100% criterion. Ericsson and Kintsch (1995) shared this capacity of 4 chunks, by asserting that a perfect recall of items was generally achieved only half of the time on average.

The limits of the memory span were also explained by Sweller (1988), who proposed the Cognitive Load Theory, which explained that the WM was limited in relation to the amount of information it could treat, and the number of operations it could realize on that amount of information. Long-term memory gave the opportunity to expand the ability of the WM, because it contained numerous schemas (similar to chunks), which were “cognitive constructs that organize the elements of information according to the manner with which they will be dealt” (Sweller, 1994, p.296). Although long-term memory could process many elements, it was not the case for WM, which could be rapidly overloaded (Paas, Renkl, & Sweller, 2003). Schema acquisition could reduce WM load because “schemas increase the amount of information that can be held in working load by chunking individual elements into a single element. Schemas not only permit long-term storage but also ameliorate working memory limitations” (Sweller, 1994, p.296). The Cognitive Load Theory implied that every learner should use his/her WM as efficiently as possible, specifically when he/she was confronted with a difficult task. According to Van Gerven, Paas, Van Merrienboer, and Schmidt (2004), “we as instructional designers need to find ways to help optimize the working memory” (p.170). For that purpose, the test developed for our research (CAM-R) proposes to offload the memory by using external memories, hence optimizing the WM, which will be further explained in the Method chapter (Chapter 8).

6.4.2.3 Development of memory span

Several authors claimed that memory span increased with age as a result of developmental improvement in the phonological store (e.g., Gathercole, 1997; Roodenrys, Hulme, & Brown, 1993), and can be considered as an indication of an individual’s mental capacity (Hume & Mackenzie, 1992). The memory span develops not only with chronological age but according to mental age as well (e.g., Bayliss, Jarrold, Baddeley, Gunn, & Leigh, 2005; Case, Kurland, & Goldberg, 1982; Hulme & Mackenzie, 1992). According to Hulme and Mackenzie (1992), the memory span is made up of approximately 4 items at 5 years old, of 5 items at 7 years old, of 5.5 items at 10 years old and of 7 items at adulthood.

Many authors studied the WM span. For instance, Rosen and Engle (1997) found that participants with high memory span tended to use strategies to enhance their performances, whereas participants with low memory span had a weaker WM capacity and were, therefore, unable to use these strategies. The strategies, that were not yet automated, required quite a bit of attention and decreased the attention required by the learning task. However, once automated, these strategies supported the learning. This explained the low correlations found between memory span and measures for learning (Cornoldi & Campari, 1998).

6.5 MEMORY IN INDIVIDUALS WITH INTELLECTUAL DISABILITY

6.5.1 Memory span in individuals with intellectual disability

It is said that measures of memory span correlates with measures of intelligence (Roodenrys *et al*., 1993) and is hence impaired in individuals with ID. This produces a gap between mental age and chronological age (Comblain, 2001; Henry, 2002; Hulme & Mackenzie, 1992; Van der Molen, Van Luit, Jongmans, & Van der Molen, 2007).

There is evidence that WM performance is strongly linked to the severity of ID. Individuals with moderate ID show some impairment in all the different subsystems of WM, whereas the impairments are less serious for individuals with mild ID (Henry, 2001; Mäehler & Schuchardt, 2009; Schuchardt, Gebhardt, & Mäehler, 2010). According to Hulme and Mackenzie (1992), the memory span of individuals with moderate ID is poor, limited to 2-3 elements (Hulme & Mackenzie, 1992) or 3-4 elements (e.g., Broadbent, 1975; Cowan, 2001).

6.5.2 Memory deficits in individuals with moderate intellectual disability

Many researchers hypothesized several deficits encountered by individuals with ID, such as production deficit, mediation deficit, or rehearsal deficit. Deficits in STM and in WM were, for example, also found in the ID population compared with typically developing individuals of the same mental age (Baker *et al*., 2011; Brock & Jarrold, 2005; Carretti, Belacchi, & Cornoldi, 2010; Carretti & Lanfranchi, 2010; Frenkel & Bourdin, 2009; Kanno & Ikeda, 2002; Laws, 2002; O'Hearn, Courtney, Street, & Landau, 2009; Purser & Jarrold, 2005; Vicari, Marotta, & Carlesimo, 2004). Each of these deficits was supposed to explain individual differences in cognitive performance. The production deficit hypothesis indicated that persons with ID were able to acquire the same strategies as persons without ID, but did not use them spontaneously (e.g., Bray & Turner, 1986; Brown, 1974; Ferretti & Cavalier, 1991; Flavell, 1970). The mediation deficit hypothesis, on the other hand, indicated that the participants were unable to use a mediator even when someone asked them to use it.

Ellis (1970, 1978) mentioned a rehearsal deficit hypothesis explaining that individuals with ID rarely used rehearsal strategies, which could enable them to maintain information longer in memory. This rehearsal strategy, however, was not used either by young children (Flavell, Beach, & Chinsky, 1966), but developed with mental age, like other memory strategies. In fact, children are going to use more and more memory strategies as they become older and are going to use them more efficiently as well, which increase their memory performances (Hulme & Mackenzie, 1992).

Individuals with ID present a shorter memory span compared with typically developing children of the same mental age (Detterman, 1979; Ellis, 1978; Hulme & Mackenzie, 1992). These individuals also present WM deficits, as they usually show lower performances in all the specific storage components described by Baddeley compared with typically developing children of the same chronological age (Baddeley, 1986; Henry, 2001;

Minear & Shah, 2006; Russell, Jarrold, & Henry, 1996; Swanson, 2006). However, the capacity of WM can be increased, notably by adapting more advanced strategies (Ericsson & Delaney, 1998).

6.6 MEMORY STRATEGIES IN INDIVIDUALS WITH INTELLECTUAL DISABILITY

Several researchers (e.g., McNamara & Scott, 2001; Minear & Shah, 2006) asserted that the WM capacity of individuals would enlarge if they would use strategies. However, individuals with ID rarely used them because of a lack of understanding of the task demands (Cowan & Alloway, 2009; Ferretti & Cavalier, 1991; Flavell, 1970; Flavell, Miller, & Miller, 2002) or an inability to organize the pieces of information (e.g., Detterman, 1979). Other authors found that individuals with ID were able to use and maintain strategies after a training session, but they still had difficulty to generalize them (e.g., Bray & Turner, 1986; Campione, Brown, & Ferrara, 1982). Nevertheless, some researchers found good maintenance effects in individuals with ID after training (e.g., Brown, Campione, Bray, & Wilcox, 1973; Brown, Campione, & Murphy, 1974; Butterfield & Belmont, 1977; Ericsson & Kintsch, 1995), specifically training based on the use of external memory strategies, but the training effects remained rather modest (Rinaldi, Hessels, Büchel, Hessels-Schlatter, & Kipfer, 2002; Tschopp, 2006).

Due to the training, some researchers demonstrated that persons with ID were able to reach an equal level of performances as untrained individuals without ID (e.g., Brown *et al.*, 1973). Besides, training enhanced the memorization and the learning of individuals with ID (Belmont & Butterfield, 1969; Borkowski & Cavanaugh, 1979; Campione *et al.*, 1982; Campione, Brown, Ferrara, Jones, & Steinberg, 1985; Paour, 2004). However, the majority of these studies concerned individuals with mild ID instead of moderate or severe ID because training these persons entailed heavy demands regarding both language and WM (Ferretti & Cavalier, 1991).

An important strategy known to improve memory performance is the external memory strategy. Intons-Peterson and Newsome (1992) defined external memories as “any device or mechanism, external to the person, whose purpose is to facilitate memory in some way” (p.101). The role of external memories is particularly relevant in our lives. They function as hints for several actions such as reorganizing, retrieving, or rehearsing, which are memory functions. They possess storage and cuing functions (Intons-Peterson & Newsome, 1992). External memories are of different types, for example: taking notes, shopping lists, diaries, photographs, pictures, drawings, maps, asking someone else to help oneself remember something, writing memos to oneself, and so on (Bray *et al.*, 1994; Harris, 1982; Intons-Peterson & Newsome, 1992). Several authors trained individuals with mild or moderate ID to use external memories with some success (e.g., Bray, Fletcher, & Turner, 1997; Bray, Huffman, & Fletcher, 1999; De Beni & Moè, 1998; Fletcher, Huffman, & Bray, 2003). For instance, Bray *et al.* (1994) successfully taught children with mild ID to place some objects at specific spatial locations, and to use external memories in order to remember where the objects were. The results showed that children tried to use strategies to remember the instructions. Even though these strategies were not the most efficient, this attempt to use them showed they have no production deficiency. Furthermore, recall increased during the testing, indicating that these children were able to represent the spatial locations with the same exactness as the other groups without ID.

Büchel and his collaborators (Büchel, 1999a; Rinaldi, 2005; Rinaldi *et al*., 2002) have applied the hypothesis proposed by Bray and collaborators to individuals with moderate ID. Rinaldi (2005) conducted a training study with thirty-six adolescents (CA = 14; IQ = 43.4). The test task consisted of remembering the location of objects (furniture, bunch of flowers, etc.) in a dollhouse. Participants were first invited to memorize all objects, their position and their orientation. Afterwards, they had to position the objects on a table out of the dollhouse. After having answered some metacognitive questions, they replaced all objects in the original location. None of the participants used spontaneously an external memory strategy. During the following training phase (6 lessons of 1 hour each lesson), participants learned to use an external memory strategy. The training was conducted with the help of a wooden crate with two floors representing the dollhouse. The participants could position all the objects in the wooden crate as they had done in the dollhouse. Participants learned to imitate the location and orientation of objects outside the initial context, which meant outside the wooden crate. The results showed that after training, one third of participants were able to use the strategy. Nevertheless, no transfer effect with the dollhouse task was found, but all participants transferred to a modified crate task. It seemed that the transfer distance from the training task to the dollhouse task was too far.

Concerning the AR area, several authors showed the effectiveness of training for solving classical analogies (e.g., Alexander *et al*., 1985, 1987; Goswami, 1992; Goswami *et* *al.*, 1998; Lifshitz & Rand, 1999; Lifshitz & Tzuriel, 2004; Robins & Mayer, 1993; Tzuriel & Galinka, 2000; White & Caropreso, 1989). For instance, Thapa (2006) used the ARLT with children with ID. Her hypothesis was that training phases were usually too short for this population (this argument was already given by Schlatter's (1999) study). A longer training phase should bring them to the same level as younger children without ID. She gave training in AR to 5 children with moderate to severe ID composing the experimental group (MA: 5.16 years old) during one year. In each lesson (once a week), she gave children exercises in AR. Learning effects were measured with the ARLT. She compared results of the experimental group to those of a control group (moderate to severe ID) without training. Results confirmed the hypothesis by demonstrating that the experimental group got significantly better performances than the control group. The performances of the experimental group were also compared to those of untrained typically developing children (N = 7; M MA = 5.19 years old). No significant differences between the two groups were found.

6.7 WORKING MEMORY, INTELLIGENCE, AND ANALOGICAL REASONING

6.7.1 Working memory and Intelligence

Several authors suggested a strong link between WM and the *g* factor[6] (e.g., Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Embretson, 1995, 1998; Engle, Tuholski, Laughlin, & Conway, 1999; Kyllonen & Christal, 1990; Siβ, Oberauer, Wittmann, Wilhelm, & Schulze, 2002). There is evidence that WM is closely linked to academic success (Alloway, 2010; Alloway & Alloway, 2010): low WM is related to poor performances on math problems (Swanson & Sachs-Lee, 2001) and to poor computational skills (Bull & Scerif, 2001; Geary, Hoard, Byrd-Craven, & De Soto, 2004). Kyllonen and Christal (1990) found a very high correlation between the WM capacity factor and the reasoning ability from .80 to .90. Engle *et al.* (1999) found similar results between WM span and fluid intelligence.

Klingberg, Forssberg, and Westerberg (2002) trained children with attention-deficit/hyperactivity disorder using WM tasks. The training lasted twenty-five minutes per session for 5-6 weeks. Before and after the training, the Raven's CPM was used to assess intelligence. The authors found a significant increase in Raven scores after the training.

[6] *Factor "g"* represents the central intellectual ability (Spearman, 1946).

However, the results could not be generalized because no control group was used. In the same manner, Klingberg *et al*. (2005) tested 10-year old children (*N* = 20) with attention-deficit/hyperactivity disorder and typically developing children (*N* = 24). The Raven's CPM was again used as an IQ measure and several WM tasks were used for training like the above-mentioned study. The results again showed a significant improvement in Raven scores. The training effects lasted 3 months for the group with attention-deficit/hyperactivity disorder. Jaeggi, Buschkuehl, Jonides, and Perrig (2008) and Buschkuehl and Jaeggi (2010) found similar results with typically developing adults. These studies demonstrated the close relationship between measures for intelligence and for WM.

6.7.2 Working memory and Analogical reasoning

Several authors suggested that a strong relationship exists between WM and reasoning with correlations in the range of .80 - .88 (e.g., Conway *et al.,* 2002; Carpenter *et al*., 1990; Engle *et al.*, 1999) and also between WM and AR, because "analogical reasoning depends on the executive resources of working memory" (Cho, Holyoak, & Cannon, 2007, p.1445). Richland, Morrison, and Holyoak (2006) mentioned an interaction between progression in AR development and developmental increase in memory capacity. Some researchers argued that the processes of linking elements together and mapping required the activation of WM. The activation of WM is assumed to depend on developmental changes in the prefrontal cortex (e.g., Baddeley & Della Sala, 1996; Morrison, Holyoak, & Truong, 2001). Recent investigations in neuroscience gave some evidence that the prefrontal cortex "which plays a critical role in the executive aspects of WM, has also been shown to mediate analogical reasoning" (Cho *et al*., 2007, p.1445).

Solving an analogy requires a person to represent each part of the matrix and to build a link between elements based on correspondences between relations (Gentner & Gentner, 1983; Gick & Holyoak, 1983), which is a process that depends on WM (Morrison, 2005). According to Primi (2001), each step of AR requires WM processes. For instance, in the encoding step all the elements composing the analogies must be stored in WM. In the mapping step, the irrelevant elements must be rejected, which requires a modification of the information already being stored in WM. In the response step, participants have "to apply a rule stored in WM to produce a new representation and then to store that result in WM until the various options can be processed" (p.46). A correlation between WM and AR has been found in the results in the Raven's Progressive Matrices because the participants must keep in mind the rules involved between the terms of the matrix, store these rules and applying them in order to find out the solution (Carpenter *et al*., 1990; Phillips & Forshaw, 1998).

6.8 SUMMARY

This chapter set out to examine the structure of memory, as well as the assessment of WM. Then, we focused especially on 3 areas: memory, strategies and training in individuals with ID.

Through the exposed studies, we saw that individuals with ID were able to use strategies in different situations (e.g., Bray *et al.*, 1997). Furthermore, training significantly improved their recall performances. When provided with an appropriate training, these individuals were able to learn AR because they were exposed to specific or general hints, which were not yet recognized by many researchers. We now know that a procedure with training and hints, and especially one with external memory use, allows participants to achieve higher performances in AR.

We also saw that individuals with ID had difficulty in doing several processes, but especially in those that required heavy demands on WM, such as reasoning (Hulme & Mackenzie, 1992). They usually forgot long instructions, and could not store information while doing another cognitive activity. The consequences of the loss of information led them to give up the task because of a memory overload, which was demonstrated by several studies (e.g., Alloway *et al*., 2009; Mulholland *et al*., 1980). An increase in amount of elements and transformations in cognitive tasks such as analogies required a larger memory space to stock all the pieces of information and thus, this increase was assumed to lead to a memory overload. A strategy for treating this overload must then be settled in order to reduce WM load (Bethell-Fox *et al.,* 1984; Primi, 2001).

The CAM test, which will be described in the next chapter, was developed with the intention to avoid the memory overload in individuals with moderate ID due to the use of external memory strategies. Moreover, this test could be considered to be attractive due to the touch screen. We already mentioned that individuals with ID had to be presented with attractive tasks because they are too often confronted with failure experiences (e.g., Agran & Wehmeyer, 2005; Siegler, 1979). In addition, the use of computer technology is more and more used to increase the capacity of persons with ID in a variety of areas (Stock *et al*., 2006; Yamamoto & Miya, 1999), which will be exposed in the next chapter.

7. COMPUTER-BASED LEARNING ASSESSMENT

7.1 INTRODUCTION

Nowadays, computers take part in every sphere of human activity: professional, leisure and especially for the search of information and for communication (Bétrancourt, 2007). Paradoxically, it is in education that computers are used the least. Hopefully, things are changing with the invention of tactile devices, such as the iPad and touch screens.

In this chapter, we will first present the growing use of computer technologies in traditional education and in special education. Then, we will expose the advantages and disadvantages of using computer technologies with individuals with ID, as well as some solutions to overtake the disadvantages. Finally, we will present the CAM test, which development represents the origin of our dissertation. To prepare for this chapter, we reviewed a quantity of studies; unfortunately, the majority of these studies concerned children with autism, which is not specifically the designated population for this study, or young children. So, we decided to focus only on the more relevant aspects of these studies, which can suit our population.

7.2 COMPUTERS IN TRADITIONAL AND IN SPECIAL EDUCATION

7.2.1 Computers in traditional education

Computers made their first appearance in education in the early 1960s and had considerably changed the conception of teachers regarding teaching: “perhaps no other technology has been as dominant in changing the contours of (…) education as the computer” (Niemiec & Walberg, 1987, p.19). Since the emergence of computers in schools, this device has been used to teach a variety of skills, such as arithmetic, problem-solving, or spelling (Mastropieri, Scruggs, & Shiah, 1997). Technology has evolved in many ways for typically developing children and for special populations as well (Shimizu, Twyman, & Yamamoto, 2003). This is because the text instructions presented on computers were generally accompanied by graphics, which help the comprehension of the text instructions (Bétrancourt, Dillenbourg, & Montarnal, 2003; Schnotz & Kulhavy, 1994). Computers were soon used by the students who perceived them as patient, nonjudgmental, and reinforcing, however, those same feelings and attitudes were not reciprocated by the teachers (e.g., Bernard-Opitz, Sriram, & Nakhoda-Sapuan, 2001; Foshay & Ludlow, 2005; Hetzroni & Tannous, 2004).

Recently, tactile devices have made their appearance in schools in addition of books: “a growing number of schools across the nation are embracing the iPad as the latest tool to teach Kafka in multimedia, history through “Jeopardy”-like games and math with step-by-step animation of complex problems” (New York Times, 2011). Some teachers even assumed that the children learned more, faster and better with such devices than with traditional material, and iPad device was said to have “brought individual technology into the classroom without changing the classroom atmosphere” (New York Times, 2011). An Australian research project has found that the use of such devices brought “improvements in all curriculum areas and also in behavior, motivation and responsibility” (Evans, 2011). The research also reported that half of the students recognized that by using the new support, they learned better, and hence, appreciated the new learning style, which in turn, allowed them to become more active learners. Of course, computers did not determine the methods or the activity, but afforded interactive activities among the school resources.

7.2.2 Computers in special education

Considering that computers offered multiple activities, researchers also used them with special populations, in order to “enhance the quality of life of students with mental retardation and other developmental disabilities” (Foshay & Ludlow, 2005, p.101). When we wrote that the computer was used in special populations, such as individuals with ID, we meant computer-based technologies, computer-based instructions, or computer-assisted instruction[7]. These technologies are twofold: the assistive technologies in which computers are, amongst others, a tool for learning, and the learning technologies, in which computers represent a way for learning and are composed of learning programs. The assistive dimension offers “interactive environments that can provide specific accommodations and accessories for enabling children with disability to access and manipulate software programs” (Hetzroni, Rubin, & Konkol, 2002, p.59). The learning dimension presents many advantages for the

[7] These terms will be used at the same level in the following paragraphs and represent assistive technologies. They can be summarized as “any device (…) that is used to increase, maintain, or improve functional capabilities of individuals with disabilities” (Wehmeyer, 1998, p.44; see also Edyburn, 2000). The last term used is technology-enhanced learning which puts the emphasis on learning and less on technology.

educational purpose, such as individualization, active learning, and motivation (Conners, Caruso, & Detterman, 1986). Besides, research supports the efficiency of computer-assisted instruction with students with ID (Wehmeyer, Smith, Palmer, Davies, & Stock, 2004).

Ramdoss and Shogren (2009) reviewed twenty-seven studies, which reported the use of computer technology with individuals with intellectual and developmental disabilities. Twenty-four of these studies suggested that computer based interventions were effective in improving functional skills in these persons, such as language and communication skills, social skills, independent and daily living skills, academic and task performance, and play skills. At the same time, other studies have shown that these technologies can increase many of the competences and skills in individuals with ID. Such skills include: augmentative communication (Hetzroni *et al*., 2002), orientation, mobility, and employment skills (Davies, Stock, & Wehmeyer, 2001); also vocabulary (Bosseler & Massaro, 2003), language and writing skills (Yamamoto & Miya, 1999); self-management skills (Davies *et al.*, 2002), such as buying merchandise in stores and using money (Foshay & Ludlow, 2005), learning daily tasks at home (Conners & Detterman, 1987); personal safety skills in order to prevent abuse (Lee, McGee, & Ungar, 1998, 2001a); problem-solving skills (Bernard-Opitz *et al.*, 2001), attention and motivation (Hetzroni *et al.,* 2002), and in the end, independence and self-confidence (Lee, McGee, & Ungar, 2001b).

7.2.3 Traditional instruction vs. computer-based instruction in individuals with or without intellectual disability

Several researchers compared traditional instruction and computer-based instruction in students with ID and found a clear preference for computer-based instruction (e.g., Fletcher-Flinn & Gravatt, 1995; McArthur *et al*., 1990). Hetzroni and Tannous (2004) reviewed many studies in which the population study was composed of students with autism. In general, the studies showed that the students gave more accurate answers, improved their reading and writing skills, and demonstrated improved behavior skills due to the computer-based instruction. Bosseler and Massaro (2003) also reported a study in which children with autism had to learn vocabulary items. They performed better in the computer condition (74%) in comparison to traditional condition (41%). Their attention and their memory were more accurate when they used the computer condition. Fitzgerald and Koury (1996) reviewed several studies and found that students with mild and moderate ID got better scores with the computer than with traditional supports. These findings were also corroborated by other authors (e.g., Shiah, Mastropieri, & Scruggs, 1995; Woodward & Rieth, 1997).

On the contrary, other studies demonstrated the superiority of tangible objects because they offered different tactile experiences to children, compared with computer interfaces; moreover, their dimensionality was not reduced to a flat screen (Olkun, 2003). For instance, Verhaegh, Resing, Jacobs, and Fontijn (2009) administered visual-spatial reasoning puzzle tasks to children between 5 and 7 years old (N = 25) in 2 conditions: tangible and virtual puzzle tasks (puzzle displayed on the computer). The results showed that the children spent less time and needed fewer instructions in the tangible condition than in the virtual condition. These results indicated that the tangible version was easier to use than the virtual version, and supported the authors' assumption, according to whom the tangible interfaces were more appropriate for training visual-spatial reasoning than the virtual interfaces. However, more children found the virtual version the funniest one.

In the same idea, Stevenson, Touw, and Resing (2011) investigated figural analogy puzzles in 2 conditions, a paper-based version and a computerized version. They administered theses analogies to 5-year old children (N = 69). The authors designed a figural analogy task with several levels of difficulty, which consisted in 2×2 matrices composed of colored animals. The relations used were composed of color, orientation, position, size, quantity and animal. In the paper-based version, the children had to select one card among several possibilities (as expressed in the Figure 7.1), placed above the matrices. In the computerized version, the participants had to use the mouse computer in order to click and to drag-and-drop the cards.

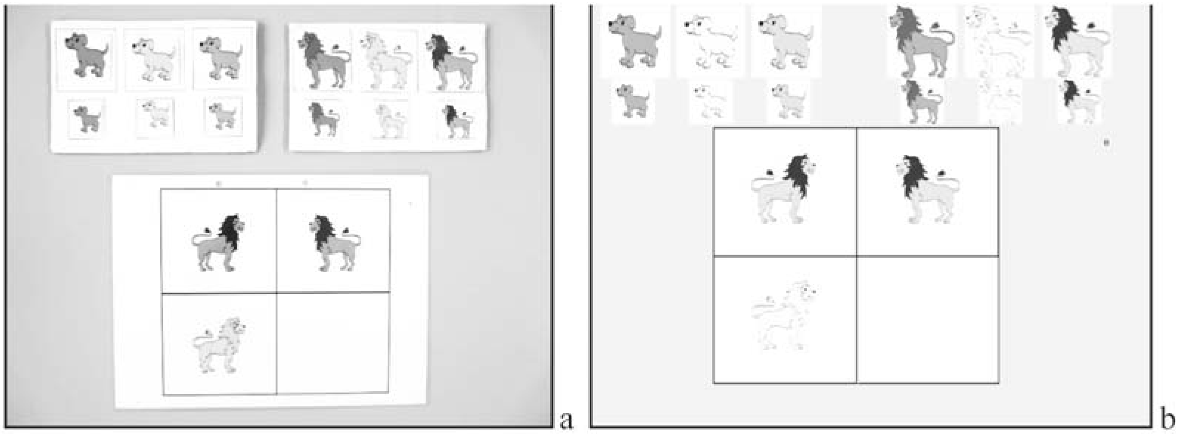

Figure 7.1 Figural Analogy task: Paper-based version (a) and computerized version (b) from (Stevenson et al., 2011, p.72)

The results showed no differences between both versions in terms of time spent for solving the items and in terms of correct answers. The authors explained these results by asserting that if the computerized version looked as much as possible to the paper-based version, then few differences in accuracy and in performances were found. These studies showed that it was not the material (tangible or computerized) which mattered, but what it could bring compared with another one.

7.3 ADVANTAGES AND DISADVANTAGES OF USING COMPUTERS WITH INDIVIDUALS WITH INTELLECTUAL DISABILITY

7.3.1 Advantages of using computers with individuals with intellectual disability

Computers entailed many advantages with regard to traditional material, especially for individuals with ID. Some competences seem particularly important to our target population, such as attention and motivation, since the use of graphics attracts attention and maintain motivation (Tversky, Bauer Morrison, & Bétrancourt, 2002). The use of computer technology possesses also other advantages. The most important ones will be described in the following paragraphs.

Computer technologies have been assumed to increase the attention of individuals with ID. This has its importance because these individuals encounter attention deficit and are easily distracted when confronted with cognitive tasks, as it has already been mentioned in the

ID chapter (Hulme & Mackenzie, 1992; Tomporowski & Tinsley, 1997). Computer-assisted instruction can precisely solve these problems by using “various visual and auditory techniques to draw attention to the learning task” (Conners *et al*., 1986, p.115). Computer technologies can also avoid this attention deficit by giving them the opportunity to perceive the pieces of information from different types of presentation. For instance, the use of sound, color or movement can retain their attention (Lee *et al*., 2001b). Indeed, these studies demonstrated that computer technologies can be used to teach concepts, such as number, shape, and color with positive results (Dube, Moniz, & Gomes, 1995; Foshay & Ludlow, 2005).

Another variable that is improved is motivation: it is known that individuals with ID have low expectations for success because they are too often confronted with failure experiences. Motivational and affective factors can decrease the cognitive processes that are required to solve a task and have a negative influence on the attitudes of persons with ID (Tassé *et al.,* 2003; Woodward & Rieth, 1997). The implication of individuals with ID in cognitive tasks can be affected, which leads to lower performances (Conners *et al.,* 1986). Motivational factors are therefore very important to consider if educators want to reduce the failure expectations, which was already highlighted by Zigler (1969). A number of studies have shown that computers are motivating, especially for individuals with ID. They are perceived as interesting, fun, and nonjudgmental when providing help or feedback, which, in turn, works to not damage their self-esteem (e.g., Bernard-Opitz *et al*., 2001; Burguillo, 2010; Cromby, Standen, & Brown, 1996; Foshay & Ludlow, 2005; Hetzroni & Tannous, 2004; Lee *et al*., 2001b; McArthur *et al*., 1990; Standen & Brown, 2005; Standen, Brown, & Cromby, 2001). In addition, the computer enables the immediate treatment of the learner’s actions, which gives an instant feedback and a personalized rhythm. Indeed, the learner works at his/her own rhythm, which is all the more important for individuals with ID.

Another advantage is to present several sources of information at the same time, like sound, images, and text, which could make learning easier and improve memory (Bosseler & Massaro, 2003). Another valuable advantage of computer technologies over traditional methods is that it avoids the use of language. Sometimes, persons with ID encounter difficulties with verbalizing their thoughts. With the help of the computer, which can present concepts with animated signs or symbols, this problem can be avoided (Lee *et al.,* 2001b; Standen & Brown, 2005).

Finally, the computer is characterized by a dynamic process and by interactivity, which allows the learner to have a choice of activities and to see immediately the interface reaction. Schneiderman (1982) and Hutchins, Holland, and Norman (1985) mentioned that when participants had a direct manipulation or involvement with the computer it gave them the feeling that they had control of themselves and the computer without needing intermediary help. Moreover, touch screen computers increased this feeling of direct manipulation with objects (Norman, 1991; Norman & Draper, 1986).

Despite all these advantages, computers can also present some disadvantages for young children and for individuals with ID.

7.3.2 Disadvantages of using computers with individuals with intellectual disability

7.3.2.1 Lack of knowledge

Computer technology has been underutilized by individuals with ID for several reasons, such as a lack of knowledge on how to use such devices. It is too complex in regards to their cognitive limitations. In addition, there is a lack of available programs especially designed for this population (Wehmeyer, 1998).

According to Wehmeyer (1998), individuals with ID and their family lack of knowledge about the availability, the cost and the full range of computer technology devices. Another disadvantage is the limited training opportunities on how to use such devices (The Arc, 2005). In fact, standard computer programs often remain too complex for individuals with ID (Stock *et al*., 2006; Wong, Chan, Li-Tsang, & Lam, 2009).

7.3.2.2 Motor skills impairments

Individuals with ID often encounter motor skills impairments (Hartman, Houwen, Scherder, & Visscher, 2010), which is also the case with paper-and-pencil material. They demonstrate lower sensory-motor and cognitive functions. Likewise, several authors argued that motor performances were linked to higher-order cognitive functions (Diamond, 2000; Ridler *et al.* 2006; Wassenberg *et al.,* 2005). These deficits make it difficult to use the computer, particularly the mouse or the joystick (Standen, Brown, Anderton, & Battersby, 2006; Trewin & Pain, 1999; Wong *et al.*, 2009), and thus, these problems lead to frustration and task disengagement. Li-Tsang, Lee, Yeung, Sio, and Lam (2007) evaluated the effects of a training program especially designed for individuals with ID (N = 59; mild ID =23; moderate ID = 31; severe ID = 5). The program entailed 3 training sets: the first concerning the use of the mouse, the second concerning the use of the keyboard, and the third concerning the access to the Internet. The training sessions lasted two times 3 hours. First findings showed positive results, and as a result of the training sessions, the participants were able to maintain the newly acquired skills 6 months after the procedure. The browsing of Internet was more difficult than the use of the mouse and the keyboard, but this result was consistent with previous findings, which demonstrated that this skill was too complex for individuals with ID (Davis *et al*., 2001), because the Internet required good reading abilities. However, the best outcome was notably the increase of participants' attention level which was attributed to the use of the computer.

Motor skills impairments have also been found in typically developing children. The mouse control disturbs and breaks the hand-eye coordination. Young children, who had not yet learn to write, experiment more difficulties than older children who can write. Preschool children seem to spend more time and to make more mistakes in movement than older children (Donker & Reitsma, 2007).

One solution to lower sensory-motor and cognitive functions was proposed by Standen, Camm, Battersby, Brown, and Harrison (2011), who used the Nintendo Wii Remote and the Nunchuk. The Nunchuk consisted

> Of a basic motion sensor (a 3 axes accelerometer) and an analogue control stick alongside a trigger button which acts as a switch. Thus it as the potential to be used as a surface mouse and/or joystick. It is simple to move and easily operable by the thumb and forefinger. (p.3)

The authors evaluated the performances of twenty-three participants (*M* chronological age = 19.17) with intellectual and physical disabilities. The study revealed faster reaction times with the Nunchuk than with other familiar devices, such as the mouse or the rollerball. However, some of the participants were unable to hold the Nunchuk without help.

The best option could very well be to use touch screen computers, which represent a valuable tool for individuals with ID. Touch screen computers reintroduce the hand-eye coordination and allow these individuals to select information directly with their fingers or with pointers. They have to be less precise than with traditional computers where they have to be very careful with manipulating the mouse (Foshay & Ludlow, 2005; Stock *et al*., 2006).

7.3.2.3 Limitation in working memory

Another difficulty, which has already been mentioned in the previous chapter, is the limitations in WM felt by individuals with ID, particularly when performing cognitive tasks. Several authors (e.g., Ozonoff & Strayer, 2001; Wong *et al*., 2009) argued that cognitive tasks administered by human means might contribute to an increase of the memory load in individuals with ID because they required a social interaction and this could "amplify a cognitive impairment that may otherwise be borderline. Human administration may be necessary, but not the only sufficient, determinant of poor performance on WM tasks and, perhaps, on executive measures in general" (Ozonoff & Strayer, 2001, p.262). On the contrary, computers offered extended graphic and dynamic features for displaying information, which could reduce the memory load and enhance the performances (Papastergiou, 2009). Wong *et al.* (2009) added that, for example,

> Adoption of a color graph design was found to reduce the cognitive load of the participants on the visual perceptual system during information processing. This in turn could free up more working memory resources for engaging in other cognitive tasks such as searching and decision-making. Based on the principles of universal design, an enhanced human-computer interface may incorporate special features that can lower the demand on attention, working memory, and visual search. (p.118)

Several of the above-exposed advantages are embedded in the CAM test, such as the touch screen computer and an adoption of a color graph design. This test was, after all, the principle focus of this dissertation. This test presented analogical matrices composed of attractive pictures displayed on a touch screen computer. All these elements were designed to reduce the WM load, and to increase the motivation and the attention span of individuals with ID as expressed in the previous paragraphs.

7.4 CONSTRUCTION OF ANALOGICAL MATRICES TEST (CAM)

In Chapter 5, we described the ARLT test (Büchel & Schlatter, 2001; Schlatter & Büchel, 2000), the results of which showed that two thirds of the participants were not able to solve analogical matrices of a second level of complexity (3 relations to infer). Büchel (2006) proposed a memory overload hypothesis. In order to prove this hypothesis, another AR test was designed by Büchel and his collaborators, but this time on a computer with a touch screen, allowing for a progressive construction of the answer: the Construction of Analogical Matrices Test (CAM; Büchel, 1999a, 2006; Angeretas & Gonzalez, 2002). This test was very important because it represented the origin of our own test. It will be presented in detail in the following chapter.

The CAM test was designed with the Authorware software (Macromedia Authorware 7 © Adobe Systems). It was composed of twenty 2×2 analogies with 7 levels of complexity (no items of the 4th and the 6th levels), the very first item was designed to familiarize the participants with the computer, the touch screen and the task demands. The 7 levels of complexity contained from 2 (first level) to 7 (seventh level) relations between the *A*, *B* and *C* terms. The items were introduced according to an increasing order of complexity.

The major distinctive feature of this test, in comparison with traditional AR tests, was to allow the participants to solve the analogies by constructing the correct answer part by part and no longer by choosing the right picture among a set of alternatives (like in the ARLT). The elements potentially constituting the answer were available permanently at the bottom of the screen. Once touched, they moved into the matrix becoming hence forth external memories, which allowed the participants not to need to memorize them anymore, as expressed in Figure 7.1 with the Baby carriage item.

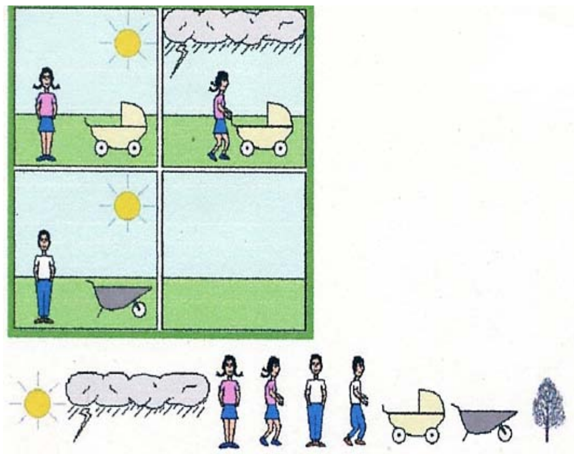

Figure 7.2 “Baby carriage” item of the CAM test (Angeretas & Gonzalez, 2002)

In fact, when the participants had discovered a relation and selected an element with their finger, they could consider a second relation without having to remember the first one. In contrast, the use of external memories was not possible in a test like the ARLT, as the answer alternatives were presented like in classic multiple choice tests. Because of the visual aids, memory overload could possibly be reduced and hence performances improved (Büchel, 2006). Besides, other authors assumed that "presenting information sequentially avoids perceptual and cognitive overload, since learners can gradually integrate the given information" (Bétrancourt, Dillenbourg, & Montarnal, 2003, p.145).

The CAM test was composed of 2 versions, one contextualized and one decontextualized. According to Büchel (1999a), items contextualization should allow a more efficient organization of information, in order to maintain it longer. In the contextualized version, items were integrated in a story. The rationale for choosing a story was that the participant would link or group the items with each other, which would offload his/her memory. In fact, elements grouping took less storage in memory than separated elements. In the decontextualized version, no story was proposed.

The test was a learning test following a hint-within-the-test procedure. It was administered individually. First of all, the matrix frame appeared and then the picture *A*. A few seconds later, picture *B* and then picture *C* appeared. Then, the elements of the answer appeared at the bottom of the screen, together with incorrect components, also called distracters, the number of which depended on the levels of complexity. Finally, a grey circle appeared on the top right of the screen. Once the participants thought the answer was correct, they needed to touch the screen with their finger in order to receive an auditory feedback. If the answer was correct, the participant heard "Well done, now do the next item". However, if it was not correct, the participant received different hints, general or specific.

The general hints could be like "No, it is not correct, look closer to the left and right changes or top and bottom changes", or "It is almost correct, but look closer to the left and right changes". The specific hints targeted each of the elements touched. For instance, in the "Apple" item, the *A* picture was a green apple, the *B* picture was a green apple with a stem, and the *C* picture was a green pear. Two relations had to be inferred, the change of fruit and the stem addition. The feedback for a correct answer was "Very good, you saw that there is an apple on top and a pear at the bottom and you also saw that there is no stem on the left but there is one on the right. Now, do the next item". If the answer was almost correct, the feedback was “That is good; you saw that there is an apple on top and a pear at the bottom. But look closer; there is a stem on the right and not on the left”. If there were no correct elements at all, the feedback was “No, it is not correct, look closer to the right. It is the same picture but we added a stem. And it is a pear at the bottom. You saw the changes: It is an apple on top and a pear at the bottom”. If the answer was still not correct after the feedbacks, the solution was given. The aim was also to encourage the participants, even if their answer was not correct. With this in mind, the test stopped after several failures, in order to avoid a feeling of failure.

Angeretas and Gonzalez (2002) administered both the ARLT and the CAM to thirty-six adolescents with moderate ID. Their results showed that the participants were able to solve analogies of a higher level in the CAM in comparison to what they accomplished in the ARLT, supposedly due to the availability of external memories. However, as Büchel (2006) criticized, these results were limited for several reasons, among which the fact that both tests were not presented in the same format (computer versus wooden blocks), questioning what really caused the difference. The results were higher in the CAM potentially because the touch screen was considered entertaining and induced higher participants’ engagement compared to the wooden blocks. Other criticisms were made against the CAM: first of all, the visual aspect was criticized because the style of the items was not uniform. The items had been drawn by several persons in different styles and all the elements were not recognized, some being too tiny to be properly seen by the participants. Secondly, the levels of complexity were criticized: the evaluation study executed by Angeretas & Gonzalez (2002) showed that theorized complexity levels did not correspond to empirical findings of the levels of difficulty. Some items of the third level of complexity were more difficult to solve than items of the seventh level of complexity. Thirdly, the distinction between conceptual and perceptual attributes had not been systematically controlled because several items entailed both attributes. Our own research will consider each of these criticisms by creating a new AR test, the CAM-R, which will be described in the next chapter.

7.5 SUMMARY

In this chapter, we reviewed studies that demonstrated the multiple advantages of using computer technologies with individuals with ID: on one hand, these technologies can be used for educative purpose, which can be highly attractive, and motivating (Bétrancourt &

Chassot, 2008); on the other hand, the standard use of computers can socialize the individuals with ID by allowing them to be part of their community. This use of computers is here synonymous with empowerment, as it allows the individuals to be autonomous and to have a better esteem of themselves (they can use the computers without the help of adults), to perceive their actions as efficient (they can immediately see the results of their actions), and to have the feeling of controlling their life (Bandura, 1997). In addition, even if computers were considered to isolate students in the past, we have to recognize that “the use of technology can create excellent opportunities for students to work together” (Ryba, Selby, & Nolan, 1995, p.82).

Even if computers could not eliminate the deficits and limited functions that were associated with ID, several studies showed that this device improved learning, promoted inclusion and enhanced performance (Foshay & Ludlow, 2005). There is now a growing recognition that computer-based activities enhance skills that are very important for the well-being of individuals with ID (Brown, 2011). Indeed, computers increase their endurance to achieve tasks due to motivational aspects (The Arc, 2005).

We also mentioned that computer technologies increased the attention span of individuals with ID, by presenting information under different types, such as sound, color or movement. All these elements were present in the CAM test, which could retain the participants’ attention. Furthermore, computer technologies have been found to be more motivating for persons with ID than other types of devices (Moreno & Saldaña, 2005), through the interactivity, the nonjudgmental feedbacks and the multiple display (e.g., Bernard-Opitz *et al.,* 2001; Foshay & Ludlow, 2005; Hetzroni & Tannous, 2004; Lee *et al.,* 2001b; McArthur *et al*., 1990; Standen *et al*., 2001). Finally, the motor limitations encountered by individuals with ID to manipulate computers was shown to be overcome by using touch screen computers (Foshay & Ludlow, 2005; Stock *et al.,* 2006), which was also demonstrated by the CAM test because the touch screen reintroduced the eye-hand coordination that was indirect with mouse interaction. In the next chapter, we will present our research questions and hypotheses, as well as the complete description of the CAM-R.

8. METHOD

8.1 INTRODUCTION

This chapter describes the different aspects linked to our study. We will successively treat the research questions and the hypotheses, the instruments used for the data collection, the project design and the description of the sample.

Briefly introduced and in order to better understand the research questions and the hypotheses, the CAM-R was composed of two versions: the first version proposed to construct the answer part by part (same format as in the CAM), whereas the second version proposed to choose the answer among several possibilities (same format as in the ARLT). We administered the CAM-R to 2 groups of participants: students with ID and children of the same mental age (4-7 year olds).

8.2 RESEARCH QUESTIONS AND HYPOTHESES

8.2.1 Research question 1

In which proportion do WM, STM and Raven CPM determine performance in AR in participants with ID and in typically developing children?

Hypothesis 1

As noted earlier in the theoretical part of this dissertation, memory and AR are linked in some ways. Therefore, we wanted to observe the links between the tasks used in the pre-test and the CAM-R test. We postulated that a link existed between the Raven CPM and both versions of the CAM-R and another link between memory and both versions of the CAM-R.

As the construction version was supposed to offload the participants' memory due to the presence of external memories, memory would less contribute to the participants' performance in this version than in the classic version. We will also observe the links between the components (Raven CPM, STM, and WM) according to the presence or absence of ID in our participants.

8.2.2 Research question 2

Is the CAM-R a valid instrument to measure AR in individuals with and without ID? How is expressed the link between the empirical difficulty of the items and the levels of complexity with regard to the number of relations and the time spent for solving the items?

Hypothesis 2

Since the construction version and the classic version of the CAM-R measure AR, we postulated a positive correlation between both versions. We also wanted to measure the concurrent validity of the CAM-R by computing correlations between each version and the Raven CPM, since they all measure AR.

Hypothesis 3

We hypothesized that the likelihood to succeed one item of one level of difficulty was higher than to succeed one item of the level above because there was always one more relation to consider at each level.

One of the CAM criticisms was that the empirical difficulty was not the same as the theoretical one. Some items at the 7th level of difficulty were easier to solve than some at the 3rd or 4th level. In the CAM-R, we attempted to avoid this problem by putting one more relation at each level.

Hypothesis 4

We hypothesized that, in both versions, the time needed to solve the items would increase from one complexity level to the next. We expected to find a linear association between time and level of complexity in each of the groups. Generally, we assumed that all participants would increase the time spent for solving the task as the task became more complex because they would need more time to find the solution.

Several authors argued that time increased according to the number of elements involved in the analogies (e.g., Arendasy & Sommer, 2005; Bethell-Fox *et al.*, 1984; Foorman *et al.*, 1985; Sternberg & Rifkin, 1979). In other words, the increase of elements and transformations led to the increase of processing time needed to solve the analogies (Mulholland *et al.*, 1980).

8.2.3 Research question 3

How does the type of versions (construction version – classic version) affect the AR performance of our participants, depending if they have an ID or not, in terms of use of external memories, number of help needed and time spent for solving the analogies?

Hypothesis 5a – Scores of participants depending on the versions

We hypothesized that all participants would obtain better scores in the construction version compared to the classic version, due to the external memories.

The construction version of the CAM-R is a version in which one can construct progressively the answer and allows not maintaining all the relations in memory thanks to the presence of external memories. The participants can treat the relations one by one without remembering those already treated. In contrast, the classic version of the CAM-R does not propose such a support; hence all the relations involved in the matrix have to be memorized in order to select the correct picture, which can overload the participants' memory.

Hypothesis 5b – Scores of participants with or without ID depending on the versions

We hypothesized that, in the construction version, participants with ID would get scores close to children of the same mental age, thanks to the external memories.

On one hand, the developmental theory, asserts that participants with the same mental age, but with a different chronological age, should obtain identical scores to cognitive tests (Hodapp & Zigler, 1997; Hodapp *et al.*, 1998). On the other hand, the difference theory asserts that persons with ID usually get lower performances compared with typically developing individuals of the same mental age, because of deficit cognitive functions, such as a lower memory span (Baumeister, 1994; Ellis, 1978). As the external memories are supposed to offload the memory, our hypothesis could give a weighty argument for the developmental theory. Thanks to the external memories, the participants with ID could get scores close to typically developing children, which will contradict the difference theory.

Hypothesis 6a- Help depending on ID

We hypothesized that participants with ID would need more help in both versions than typically developing children. This means that typically developing children would succeed on more items on the first attempt than participants with ID. However, if this hypothesis is correct, the help would be more useful for participants with ID. Consequently, they would get scores close to children with the same mental age.

Several studies showed that individuals with ID encounter difficulties with AR tasks compared with typically developing individuals because of deficit cognitive functions, such as limitations in WM, lack of comparative behavior, non-use of strategies, deficit of attention, or low motivation (e.g., Agran & Wehmeyer, 2005; Alloway *et al.*, 2009; Büchel, 2007; Halford, 1993; Hulme & Mackenzie, 1992; Lifshitz *et al*., 2005). These deficits might prevent the participants with ID from being successful at the first attempt.

Hypothesis 6b – Help depending on the versions

We then assumed that each group would require more help in the classic version than in the construction version.

This hypothesis is justified by the fact that the classic version was perceived as being more complex than the construction version because it did not contain external memories and then overloaded the memory.

Hypothesis 7a – Time depending on ID

We hypothesized that, in each level, participants with ID would need more time to solve analogical matrices than the typically developing children.

As the test becomes more complex, there are always more and more relations to treat and elements of answer/pictures to consider, which require more time. Several authors demonstrated that individuals with ID tend to need more time for solving the analogies than typically developing children (e.g., Jensen *et al*., 1981; McConaghy & Kirby, 1987a; Sternberg & Nigro, 1980). In addition, persons with ID tend to demonstrate slower reaction times compared with typically developing children (Hulme & Mackenzie, 1992). As the same is true for young children, we also expect that these children will spent more time for solving the analogies than older children (Foorman *et al*., 1985).

Hypothesis 7b – Time depending on the versions

We also hypothesized that the items of the construction version will need more time to be solved than the items of the classic version.

Our hypothesis is justified by the fact that the elements within the answers of the construction version are greater in numbers than the pictures in the classic version, except at the first level. Moreover, Sternberg and Rifkin (1979) demonstrated that separable attributes took more time to be considered than integral attributes.

8.2.4 Research question 4

According to the literature exposed in the theoretical part, the difficulty of analogies lied in several components, such as the familiarity of attributes and relations and the type of relations. In what extent do these components influence the AR performances of our participants?

Hypothesis 8 – Reasoning by analogy or by association?

We hypothesized that the majority of our participants would reason by analogy and not by association because all our analogies were designed with familiar elements and relations.

Our hypothesis is justified by Goswami and Brown's studies (1989, 1990), which have shown that analogies composed of familiar attributes and relations enabled young children to reason by analogy and not by association. Moreover, familiar material is better stored in WM than unfamiliar material (Ericsson & Delaney, 1998). Therefore, we expect that the association false elements or pictures will rarely be chosen by the participants.

Hypothesis 9 – Perceptual vs. Conceptual items

We hypothesized that in both versions the perceptual items would be more successful than the conceptual items for all groups.

Conceptual items require higher-level processes than perceptual items because they refer to abstraction of relations (e.g., cut, open, fall, etc.), whereas perceptual items are composed of elements that are immediately visible (e.g., color, shape, size, etc.). In addition, several authors demonstrated that conceptual analogies were more difficult to solve than perceptual analogies (Carpenter *et al.*, 1990; Tzuriel, 2007; Tzuriel & Galinka, 2000).

We also wanted to know if there was a developmental progression from perceptual characteristics to conceptual characteristics, as stated by Gentner (2003; Gentner & Ratterman, 1991). Is this argument is correct, then young typically developing children would consider more perceptual items than older typically developing children, as for them should consider both categories in the same manner.

8.3 THE INTRUMENTS

In order to evaluate the performances of our participants, we applied several instruments in our research. Before describing these instruments, it is important to mention that we used, in a preliminary phase, the first eight items of the CAM-R, in order to know if the selected participants understood the purpose of AR tasks and if they were able to manipulate the touch screen. Following these eight items, the participants who did not understand the proposed task were excluded.

Two other instruments were used, one for measuring mental age on an IQ test, and the other for measuring memory capacity. Both these instruments were employed for matching the participants. Finally we applied both versions of the CAM-R for measuring the AR ability.

8.3.1 Raven's Colored Progressive Matrices

Despite the fact that we criticized the use of static tests with disabled individuals in the second chapter, we decided to apply one of them as a measure of mental age. The Raven's Progressive Matrices (Raven, Court, & Raven, 1990; Raven, Raven, & Court, 1998) was chosen because it measured AR like the CAM-R. The Progressive Matrices were defined as "a test of a person's present capacity to form comparisons, reason by analogy, and develop a logical method of thinking regardless of previously acquired information" (Raven, 1938, p.12). This test was considered to provide one of the most reliable measures of the "*g*" factor (Carpenter *et al.*, 1990; Spearman, 1946). In addition, its nonverbal format supported our choice because several participants with moderate ID could not speak. We used the Colored (CPM) version since it was designed for children and for individuals with ID.

The CPM was broadly recognized as a culture-fair test of non-verbal intelligence for young children. This paper-and-pencil test had no time limit and comprised thirty-six items in 3 sets with twelve items per set (see Appendices, section A for the 36 items). The first items of the CPM were composed of a big picture in which a piece was missing. The participants needed to find the missing component amongst 6 possibilities. After several items, the participants were presented with AR analogies. Generally, each item consisted of abstract shapes and elements, which were organized in a 2×2 matrix format, as illustrated in Figure 8.1.

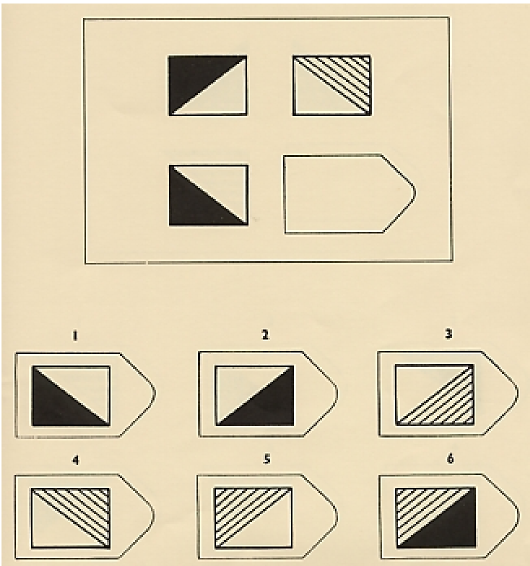

Figure 8.1 Item B6 of the CPM

The fourth cell on the lower right corner was always empty. The participants needed to abstract the rules from the other 3 cells in order to find the solution. The items were easy to begin with, but became more and more difficult as the test progressed (Meo, Roberts, & Marucci, 2007).

The CPM produced a single raw score that could be converted into a percentile score based on normative data, which concerned children between 4 and 11 ½ years of age. For interpretation, someone above the 95th percentile was intellectually superior; someone above the 75th percentile was above average; someone between the 25th and 75th percentiles was intellectually average; someone below the 25th percentile was below average; and someone at or below the 5th percentile represented an intellectual impairment. With the raw scores, it was then possible to define the participants' mental age, which was the age at which the mean percentile score was equal to their raw score (Raven *et al*., 1990).

8.3.2 Short-term and Working memory tasks

In order to measure the memory span range of our participants, we used WM tasks as well as STM tasks (Lanfranchi *et al*., 2004), both verbal and visuospatial. As said in the Memory chapter (Chapter 6), Cornoldi and his colleagues (Cornoldi *et al*., 2000; Cornoldi & Vecchi, 2003) contradicted Baddeley's model and proposed memory tasks that suited more individuals with ID.

Lanfranchi *et al.* (2004) used these tasks with children with Down syndrome, fragile X syndrome, Prader-Willi syndrome and Cornelia de Lange syndrome, as well as with typically developing children between 4 and 6 years old. These populations shared approximately the same mental age as our participants, which subsequently, led to the use of the material format provided by S. Lanfranchi (see Appendices, section B).

Each task entailed a total of 8 points and required different degrees of control: the STM tasks required low and medium control, and the WM tasks required high control.

8.3.2.1 Short-term memory tasks

Two STM tasks were verbal (Word Span and Selective Word Recall). They consisted of: 1) Word Span task, which required low control because the participants only needed to use a simple operation; 2) Selective Word Recall task, which required medium control because the participants needed to select pieces of information and control interference from irrelevant information.

The material was composed of eleven two-syllable words that were familiar and concrete to the children of their studies. In all the tasks the experimenter presented the words verbally at a rate of 1 word per second. The authors choose this method "because a pilot study had shown that children were more comfortable and better able to do the tasks if the material was presented verbally by the experimenter rather than by a tape recorder" (p.459).

We translated the tasks into French in order to administer them to our participants. However, the eleven words, which were originally two-syllable words in Italian (in the original version), sometimes only translated into being one-syllable words in French. Thus, we decided to change the one-syllable words into two-syllable words that were familiar to children. The original words (in Italian) were: house, mum, dad, dog, cat, apple, grandma, ball, moon, sun, and pear. After having a discussion with Fredi Büchel and Mireille Bétrancourt, we decided to change dog into boat, cat into car, pear into banana, apple into lemon, grandma into mouse, and moon into cloud. Our choices were confirmed and validated by the support workers of the 2 special institutions that we selected (see the population procedure).

Instructions and practice trials preceded each task. The task began only when the child had understood the instructions. In order to avoid frustrations among the participants, the task was stopped if the participants failed on both lists of the same length. If this was the case, the remaining items were considered incorrect. The administration of these tasks lasted between 20 and 30 minutes, with short breaks if needed.

Two STM tasks were visual (Memory for Positions and Selective Positions), and two were spatial (Pathways and Starting Positions). The Memory for Positions task required low control; the Selective Positions required medium control; Pathways task required low control, because it required "maintenance of visual information in a passive store" (Lanfranchi & Vianello, 2008, p.213). This task was an adapted version of the Corsi Block task, because the Corsi Block was considered too difficult for the Lanfranchi's population study. The Starting Positions task required medium control.

8.3.2.2 Working memory tasks

The WM tasks were considered to be the tasks with the highest degree of control, because they required a dual task requirement. One task was verbal (the same material used in the STM tasks), and the other task was visuospatial (see Appendices, section B).

As it was the case for the STM tasks, instructions and practice trials preceded each WM task. The WM tasks began only when the child had understood the instructions. In order to avoid frustrations among the participants, the task was stopped if the participants failed on both lists of the same length. In this case, the remaining items were considered incorrect. The administration of these tasks lasted between 20 and 30 minutes, with short breaks if needed.

After a discussion with S. Lanfranchi, it was decided to produce 2 total scores: one for the 2 WM tasks with a total of 16 points (8 points for each task), and another for the 6 STM tasks with a total of 48 points (8 points for each task). Even though the total scores were not equal (16 vs. 48), it was better to differentiate the STM tasks and the WM tasks, because these scores would probably give an indication regarding our memory load hypothesis. Although the notion of control was present in all these tasks, we decided not to talk about it, also in regards to the topic of this dissertation.

8.3.3 The Construction of Analogical Matrices Test-Revised (CAM-R)

For this entire subchapter, we will only consider the main pieces of information. We will not describe the creation of the items of the CAM-R in details because this was described in a previous publication (see Borel, 2008).

8.3.3.1 The CAM test: limitations

As mentioned in the previous chapter, the CAM test comprised several limitations; among them was the visual aspect of the items. The items had been drawn by several persons in different styles (drawings, pictures, etc.), and some of the elements were too tiny to be seen by the participants. The small size of the elements prevented the participants to touch them with their finger, all the more so with individuals with moderate ID who often had fine motor skill problems and, as a consequence, could not always touch or manipulate small objects. A wrong answer could be due to these failures and not to the participant's reasoning.

Secondly, the levels of complexity were criticized: an evaluation study showed that the theoretical complexity levels did not correspond to empirical findings of the levels of difficulty. Some items of the third level of complexity were more difficult to solve than items of the seventh level of complexity. Also, several items included an adding relation, which was not considered to be an analogical relation. The participants did not need to reason by analogy with this relation, but just needed to copy the adding elements. The "Table" item in Figure 8.2 illustrates this problem.

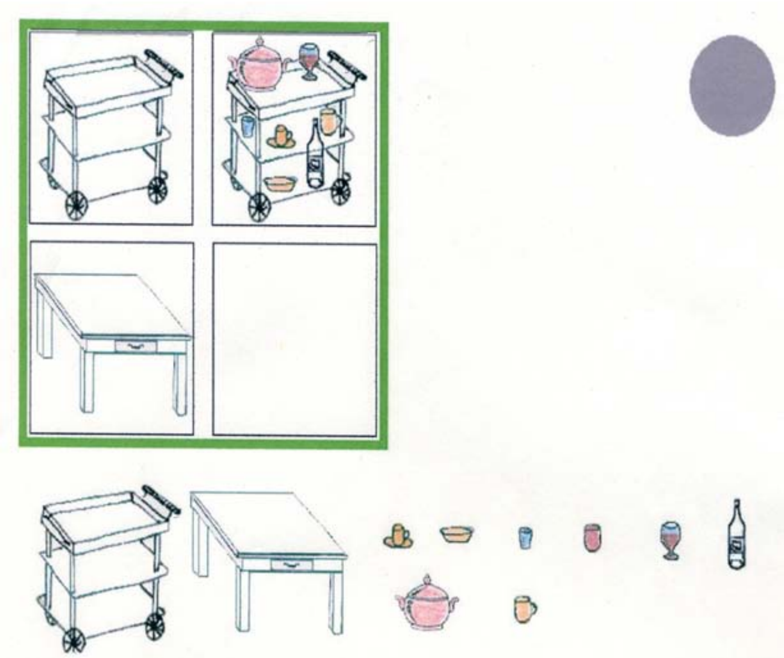

Figure 8.2 “Table” item of the CAM test (Angeretas & Gonzalez, 2002)

The “Table” item was a part of the seventh level of difficulty. In this item, there were 7 adding relations. The participants only needed to copy the 7 elements present in the B term of the matrix and to place them on the table in the D term. No AR was necessary in this item, despite the fact that it was supposed to be one of the most difficult items.

Thirdly, the authors (Angeretas & Gonzalez, 2002) decided to create their items with either conceptual or perceptual relations. However, in some items, the distinction between conceptual and perceptual attributes had not been systematically controlled because several items entailed both relations, which prevented them to know if the perceptual relations were easier to solve than the conceptual ones or the opposite.

Our own research will consider each of these criticisms by creating a new AR test, the CAM-R, which will be described in the following paragraphs.

8.3.3.2 Answers to the limitations of the CAM test

The CAM-R is composed of 2 versions, a classic and a construction one, which will allow the participants’ scores to be compared by using an identical presentation format (i.e., a computer with a touch screen). This will answer the main criticism made to the previous research (Angeretas & Gonzalez, 2002), which compared the usage of a wooden blocks test with a computerized test.

Concerning the first limitation, the visual aspect of the items, our decision was to adopt a unique style in the CAM-R for a better consistency. It was also decided to avoid tiny elements. In order to keep the images consistent, we chose a professional artist (Borel, 2008) to draw all the pictures under our direction.

Concerning the second limitation, the item difficulty, our decision was to avoid adding relations in the CAM-R. In addition, it was decided that in both versions, the number of elements should grow according to the levels of complexity, which allowed us to improve the link between the empirical difficulty of the items and their level of complexity. The familiarity of elements also took place in the item difficulty. In a pilot study (Borel, 2008), we carefully checked that all relations used (color, shape, size, etc.) were known by our participants. Each item[8] was presented to young children (N = 8; 4-6 years) and to students with moderate ID (N = 8), who shared approximately the same mental age as our participants.

Finally, concerning the third limitation, the conceptual and perceptual relations, we decided to separate both kinds of relations distinctively. Each item was composed either by conceptual relations (e.g., cut, open, eat, walk, fall, wet, type of objects, gender, weather) or by perceptual relations (e.g., color, shape, size, presence).

8.3.3.1 Creation of the items

8.3.3.1.1 Analyze criterion

In order to design the CAM-R, we carefully examined each item of the CAM, in order to observe if they could be decomposed in several elements for the construction version. We eliminated many of the items and also those comprising the adding relation. The examination of each item and the discussion explaining this examination were reported in Borel (2008).

[8] There were 36 items in the pilot study (Borel, 2008). The elements that were not recognized by one or more participants were either modified, or excluded. We selected 24 items that were all understood by the participants.

8.3.3.1.2 Modification of the remaining items

The main problem of the remaining items was that they comprised conceptual and perceptual relations at the same time, which we wanted to avoid. For instance, the color relation, which was defined as a perceptual relation, could also be considered to be a conceptual one. For example, if we had a blue sky representing the day and a black sky representing the night, this could be considered as a conceptual relation, which could be perceived as being the difference between the day and the night, or as a perceptual relation, which could be perceived as being the difference between blue and black.

To avoid this kind of issues, we decided that the sun should represent the day and the moon, the night. That way, the color of the background did not need to be changed. It was clear that it was almost impossible to create an item entirely perceptual or conceptual without putting some elements of the other category, especially with items that were composed of several relations like ours. Tzuriel (2007) also mentioned this difficulty regarding 1 or 2 of the relations in the test, as the CCPAM analogies were composed of only 1 or 2 relations. As our analogies were composed from 2 to 5 relations, we were confronted to the same problem.

8.3.3.1.3 First version of the items

We kept several items concepts from the CAM and then modified them and created new ones (for a complete description, see Borel, 2008). As mentioned before, we carefully checked if each relation and each element involved was understood by our population, as we followed Goswami and Brown’s (1989, 1990) assumption that young children were able to reason by analogy as long as they were familiar with the relations involved. The thirty-six items were then presented to young children (4 years old) and to adolescents with moderate ID (Borel, 2008).

Borel’s (2008) master thesis showed that some elements were not recognized by our population. For instance, we represented the sun with a yellow circle, but it was perceived as being a full moon. Because of that, we decided to add rays of sunlight. Secondly, the left-right relation was not recognized by the young children, as already expressed in the literature (e.g., Goswami *et al*., 1998), so we decided to remove the items comprising this relation. The final version was composed of twenty-four items (twelve perceptual and twelve conceptual), which are listed in the subchapter 8.3.3.5 and presented in the Appendices). The first 8 items were designed to train the participants how to solve analogies and to familiarize them with the touch screen computer.

8.3.3.2 Description of the versions

Each version of the test was composed of analogies presented as 2×2 matrix format in a concrete figurative modality shared among four levels of complexity. In the CAM, they were more levels of complexity, but in the last levels (5^{th} to 7^{th}), this complexity was mostly represented by non-analogical relations (see Figure 8.2).

In the construction version, answer *D* needed to be constructed with the elements available permanently at the bottom of the screen, together with the incorrect elements. In contrast, in the classic version, answer *D* needed to be chosen among several pictures, only one being correct. In both versions the elements potentially constituting the answer were available permanently at the bottom of the screen. Once touched, the elements (in the construction version) or the pictures (in the classic version) moved into the matrix.

The advantage of the construction version is that it allowed the participants to consider one relation after another, without remembering those previously taken into account. Once they discovered one relation, they touched one element located at the bottom of the screen, which moved into the *D* zone of the matrix, therefore becoming an external memory. The “slide” movement presents a major advantage. As said before, invididuals with ID and young children could have motor skills impairments. With the “slide” movement, they just had to touch an element with their finger; they did not have to drag-and-drop it, which was a more difficult movement for young children compared to a simple pointing (Joiner, Messer, Light, & Littleton, 1998).

Figure 8.3 presents the “Ice-cream” Item in the construction version and Figure 8.4 presents the same Item in the classic version.

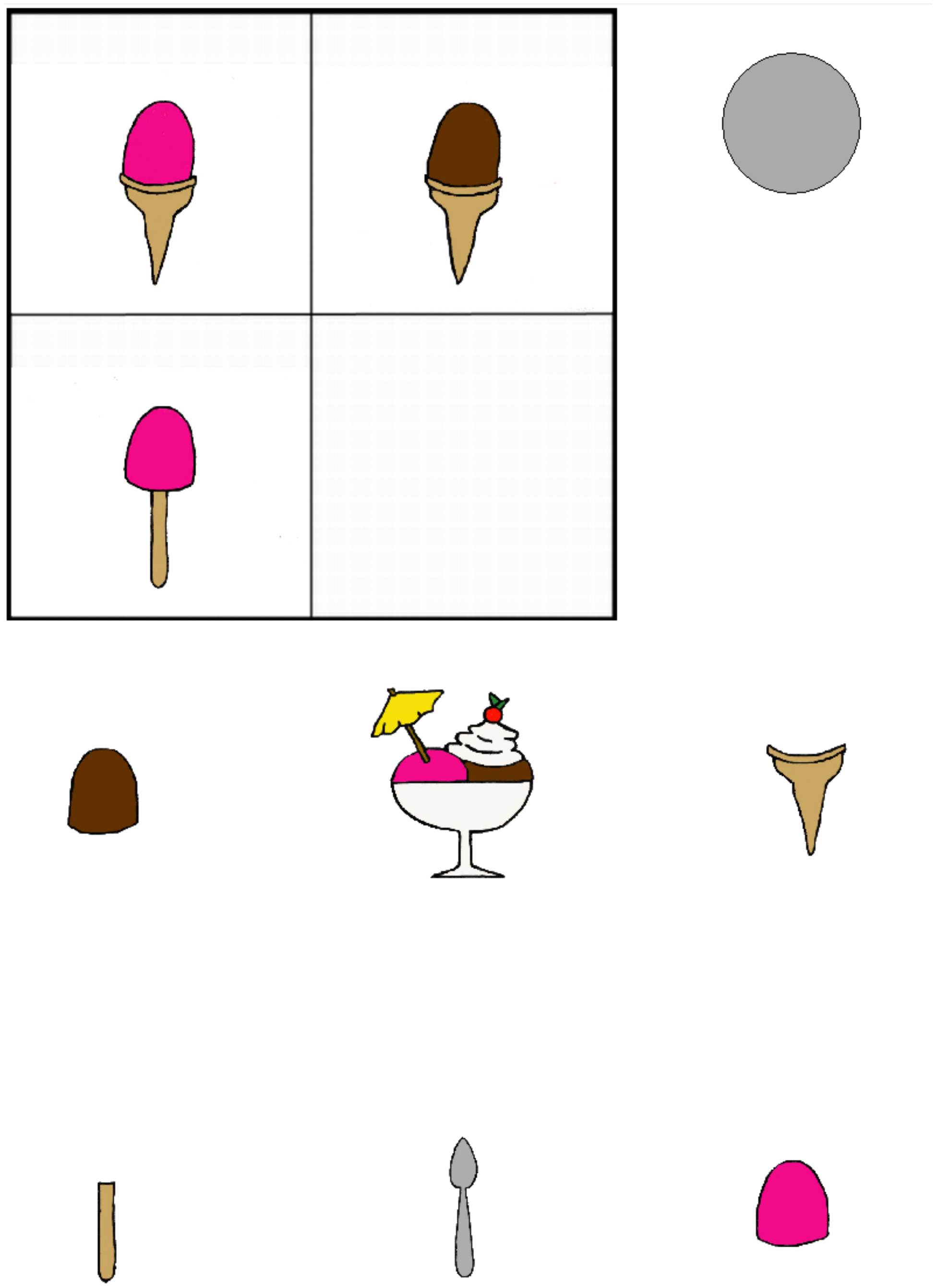

Figure 8.3 “Ice-cream” Item (CAM-R) in the construction version

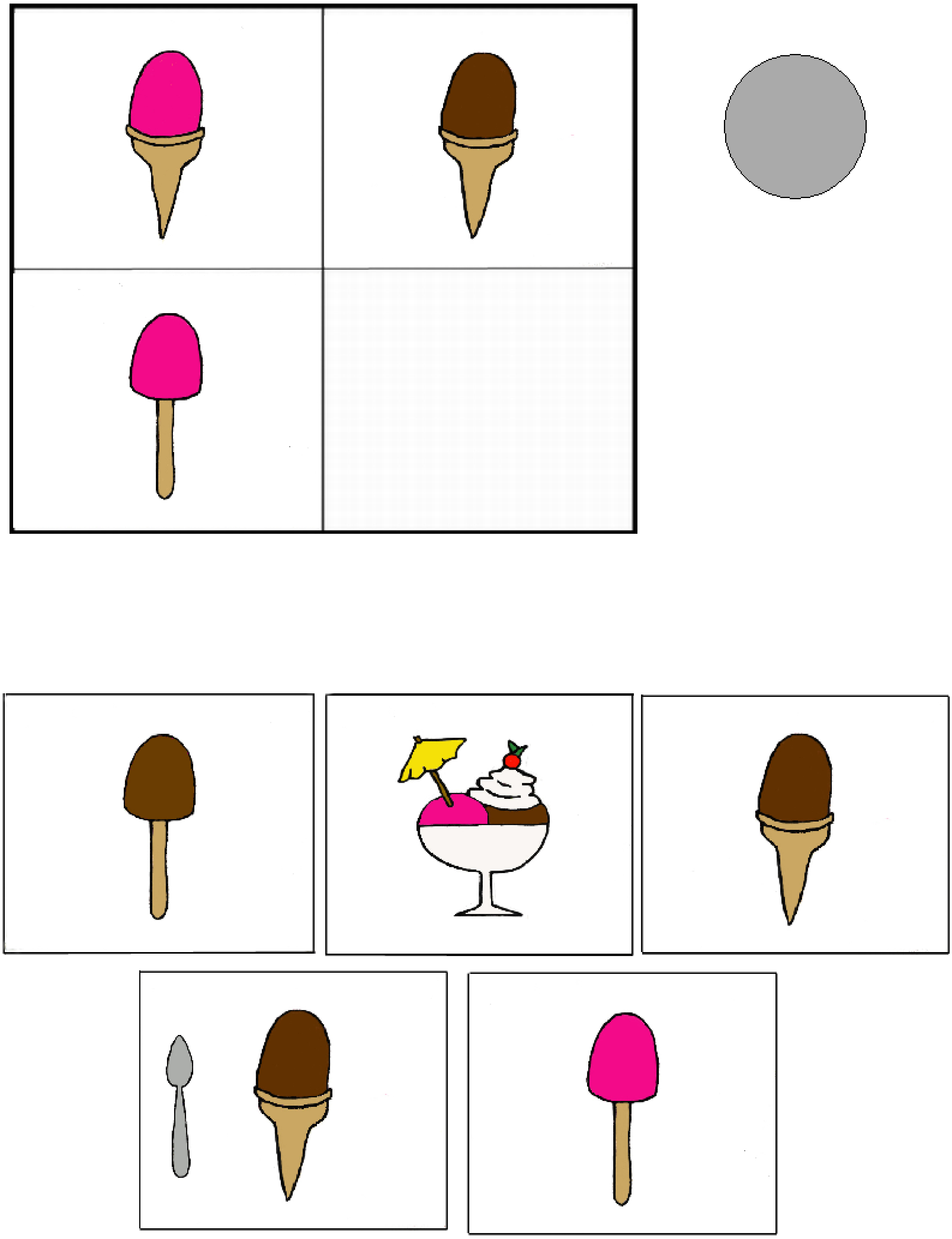

Figure 8.4 “Ice-cream” Item (CAM-R) in the classic version

Each CAM-R version was composed of 4 levels of complexity, characterized by the number of relations. In both versions, the number of elements (in the construction version) and the number of pictures (in the classic version) of each item grew according to the levels of complexity. The number of relations between the *A, B,* and *C* terms for each level is shown in Table 8.1.

Table 8.1
Number of relations between the A, B, and C terms for each level and for both versions

	1st level	*2nd level*	*3rd level*	*4th level*
Number of relations between the A-B terms	1	2	3	3
Number of relations between the A-C terms	1	1	1	2
TOTAL by item	2	3	4	5
TOTAL by level	8	12	16	20

Participants were confronted with matrices presented on a touch screen. The *A*, *B* and *C* terms of the matrix appeared one by one. The answer *D* needed to be found by discovering the relations existing between these 3 terms. In the first level, participants needed to infer 1 relation between the *A*-*B* terms and another between the *A*-*C* terms. There were 2 *A*-*B* relations and 1 *A*-*C* relation, 3 *A*-*B* relations and 1 *A*-*C* relation, and 3 *A*-*B* relations and 2 *A*-*C* relations respectively in the second, third and fourth (highest) levels, as summarized in Table 8.1.

There were a total of fifty-six relations. In order to avoid possible frustrations among the participants, no more than 5 relations were used, which probably was a little more than their memory span could maintain (approximately 3 elements; Cowan, 2001; Hulme & Mackenzie, 1992). Twenty-four items composed the final version, among them the first 8 were training items (4 at the 1st level with 2 conceptual and 2 perceptual; 4 at the 2nd level with 2 conceptual and 2 perceptual) used to familiarize the participants with the touch screen and the task demands.

8.3.3.3 Associative elements

The possible answers (separated elements in the construction version and pictures in the classic version) were available at the bottom of the screen together with incorrect elements, which were associative elements or associations (1 or 2 per item). In the Figures 8.3 and 8.4, the associative elements were a spoon and an ice-cream bowl. We decided to put these associative elements into the possible answers in order to observe if our participants were attracted by them by using associative reasoning or if they were really reasoning by analogy. Goswami and Brown's (1989, 1990) studies have shown that if analogical items were composed of familiar relations very young children were able to reason by analogy and not by association.

8.3.3.4 Perceptual and conceptual relations

The choice of conceptual and perceptual relations for the CAM-R was based on Tzuriel & Galinka's (2000) and also on Büchel's (2006) distinction. As mentioned in Chapter 5, Tzuriel and Galinka (2000) designed the CCPAM that was composed of 2 subtests, one with perceptual relations, and the other with conceptual relations. The authors proposed 3 perceptual relations: *existence* (appearance or disappearance of objects), *opposite* (object location), and *difference* (position, color, type of object, and number). They also proposed 3 conceptual relations: *part-whole*, *categorical*, and *functional*.

Büchel (2006) discussed Tzuriel and Galinka's choices concerning the different types. He agreed with the 3 conceptual relations *functional*, *part-whole* and *category*, as well as for the perceptual relations *opposite*, *existence*, *position* and *color*. However, he did not agree that *type of object* and *number* were perceptual relations. He stated that "numbers represent quantitative entities, and the possible relations between numbers are defined by arithmetical operations which are conceptual relations" (p.74). Moreover, he defined *type of object* by the fact that every object was a specific instance of a whole class of entities. In his opinion, classes had conceptual relations. The fact that the entities were limited to objects and that objects were perceivable ones did not change the conceptual nature of classes (p.74).

For the CAM-R test, we defined the following relations as perceptual: presence and difference (change of color, size and shape). We could not select the "opposite" relation because the slide function of the software Authorware put the objects directly in their correct place, hence we could not have the relation "under/over" (ex., under a table/over a table).

Regarding the conceptual relations, we selected functional (cut, open, eat, walk, fall, wet); categorical: weather (day/night and good/bad), human (man/woman and child/adult), ground, and setting; and type of object.

8.3.3.5 Final version of the items

The twenty-four items of the CAM-R are presented in Appendices, section C. The Table 8.2 recapitulates the complexity levels, the type of items (perceptual or conceptual), the total number of elements (including the associative elements), the relations theme, and the associative elements in the order of appearance of the items.

As shown in this table, the perceptual items were administered before the conceptual items. Our choice depended on Tzuriel & Galinka's (2000) procedure regarding the CCPAM, who demonstrated that learning of conceptual analogies was transferred to perceptual analogies, but not vice versa (Tzuriel & Galinka, 2001). In order to avoid a transfer effect, we estimated that it was better to administer the perceptual items before the conceptual items.

Table 8.2
Twenty-four test items of the CAM-R.

Item	***Level***	***Type of items***	***Number of elements + associations (CO)***	***Number of pictures (CL)***	***Relations***		***Associative elements***
					A-B	***A-C***	
Ice Cream	Training-1st level	P*	6	6	Color	Shape	Spoon + Ice cream bowl
Flower	Training-1st level	P	6	6	Size	Shape	Leaves + Watering can
Lemon	Training-1st level	C**	6	6	Action	TO***	Lemon squeezer
Candle	Training-1st level	C	6	6	Action	TO	Lamp + Match

Girl	Training- 2nd level	P	7	6	Color + Shape	E****	Table + Jump rope
Rabbit	Training- 2nd level	P	7	6	Color + E	Size	Birdcage + Bunch of carrots
Ladybird	Training- 2nd level	C	7	6	TO + Day/Night	TO	Caterpillar
Beach	Training- 2nd level	C	7	6	Gender + TO	Action	Plastic duck
Pear	1	P	6	6	Color	Size	Half Pear
Bike	1	P	6	6	Size	Color	Chair + Motorbike
Carrot	1	C	6	6	Action	TO	
Book	1	C	6	6	Action	TO	Page
Swimming Pool	2	P	7	6	Shape + Color	Shape	Swimsuit
Truck	2	P	7	6	Size + Pr	Color	Car + Trailer
Window	2	C	7	6	Action + Gender	Weather	Ball
Mouse	2	C	7	6	TO + TO	Action	Bunch of carrots
Snail	3	P	9	7	Size + Color + Size	Pr	Caterpillar + Branch
Car	3	P	9	7	Color + Shape + Pr	Size	Motorbike + Backpack
Dog	3	C	10	7	Weather + Action + Action	TO	Mouse + Kennel
Umbrella	3	C	9	7	Weather + Action + TO	Gender	Bus
Clown	4	P	12	8	Shape + Color + Pr	Shape + Size	Balloons + Circus tent

Train	4	P	11	8	Color + Pr + Pr	Size + Shape	Rail + Driver
Baby carriage	4	C	11	8	Action + Weather + TO	Gender + TO	Baby
Tree	4	C	12	9	Weather + TO + TO	Action + Action	Basket

*P = Perceptual item; **C = Conceptual item; ***TO = Type of Object; ****Pr = Presence

CO = Construction version; CL = Classic version

8.3.3.6 Procedure for the implementation of the CAM-R

The final twenty-four items of the CAM-R were first presented on a paper-and-pencil format in Borel’s (2008) study. Then, they were scanned so that they could be used in a computerized version. However, the colors were blurred because of the scanning procedure. Adobe Photoshop CS2 was used to accentuate each color and to outline the contour of each element. Then, the items were computerized with the Authorware software (Macromedia Authorware 7 © Adobe Systems)[9] on a touch screen computer (DELL Latitude XT2 Tablet PC).

The CAM-R followed an individual administration. Each participant was seen individually by the same person (the author of this dissertation) 5 times in all, in a quiet room, free from disturbance. The largest amount of time spent for each stage was approximately thirty minutes. According to the support workers and teachers, this amount of time was already twice or three times more than the duration of the usual daily tasks administered in the institutions or in the schools. So, testing took large part of the attention span of the participants.

Testing did not start before each participant understood the task demands. For those who could speak, they expressed what they understood and what they did not. For those with poor verbal ability, a look or a sign was sufficient to know their level of understanding.

[9] It took one year to learn how to use the Authorware software in order to computerize the test. After this year, the twenty-four items were available in both versions on the touch screen computer.

Test items of the CAM-R were preceded by 8 training items (the same as in the preliminary phase), allowing the familiarization with both the task and the touch screen. In addition, the participants had the opportunity to solve the test items a second time if they failed at the first attempt, which meant if they did not find the right picture (in the classic version) or if they did not choose all the necessary elements of the answer (in the construction version). In this situation, they received a feedback composed of standardized help, like "You saw that the color changed between *A* & *B*, but have a closer look to the change between *A* & *C*" and they could try the item a second time. We chose to give a feedback because this procedure has proved to be a prerequisite for improving AR in young children (e.g., Cheshire, Ball, & Lewis, 2005) and therefore in students with moderate ID. Moreover, we chose to give a verbal feedback because a previous study showed that children were more comfortable and better able to solve the tasks if the feedback was presented verbally by the experimenter rather than by the computer (Lanfranchi *et al*., 2004). The standardized instructions are presented in Appendices, section D.

8.3.3.7 Test score reliability

We measured the reliability of each version. The sixteen items of the construction version showed high internal consistency, with a KR-20[10] of .91. The 8 perceptual items showed a lower internal consistency, with a KR-20 of .70, whereas the 8 conceptual items showed a higher one, with a KR-20 of .87.

Also the sixteen items of the classic version showed a high internal consistency, with a KR-20 of .94. The 8 perceptual items also showed a higher one with a KR-20 of .80, the same was true for the 8 conceptual items but with a higher KR-20 of .89.

8.3.3.8 Scoring of performance, errors, and time

As said earlier, each version was composed of sixteen items (4 items in each level of complexity), which brings a total of fifty-six relations. We decided to attribute 1 point for each correct relation, which brought the maximum number of points at fifty-six like the total number of relations (see Table 8.1). We chose to proceed in this way, in order to give value to

[10] For dichotomous variables we usually use Kuder-Richardson 20 test (KR-20), which is comparable to Cronbach's alpha.

our participants' reasoning. Indeed, if we had decided to give 1 point for one item that was entirely correct and 0 point for one entirely wrong, which was our first intention, we would have underestimated the answers of these types: for example, 2 correct relations out of 3, or 3 out of 5.

Number of points was independent of the number of trials. For instance, for a first level of difficulty, if one relation was succeeded at the first trial, the participants received 1 point. If both relations were succeeded on the second trial, they received 2 points. There will be a double analyze: one for each trial. Thus we will notice how much successful relations there are at the first level and how much at the second level.

The Authorware software (Macromedia Authorware 7 © Adobe Systems) recorded the number of correct and wrong relations, as well as the time spent (expressed in seconds) to solve each item for all participants.

8.3.4 The CAM-R design

The CAM-R test started in September 2008 with the administration of the 8 training items (Stage I). November and December 2008 were spent on administering the Raven CPM and the memory tasks (Stage II). From January to May 2009, we administered the 2 versions of the CAM-R (Stage III).

Stage I

The preliminary phase consisted of administration of the first 8 items of the CAM-R. These items were used to check if the participants understood the tasks demands (to reason by analogy) and if they were able to manipulate the touch screen efficiently.

Stage II

The pretest was also composed of 2 other tasks: the Raven CPM and the memory tasks. We administered the Raven CPM in order to obtain the percentile score of all participants, which was considered as a basis for mental age. Then, the STM and WM tasks were administered in order to situate their memory performances.

Stage III

At least two months after, both versions of the CAM-R were administered in a counterbalanced order. We checked that there were no significant differences caused by the order of the administration (interaction between the order and the versions: $F<0$).

Each participant was randomly assigned to receive one version and then 6 weeks later the other version. For the first version, we began with ID participants, then with the typically developing children. When the first round was over, we began again with ID participants for the other version, and finally with the typically developing children. The 6 weeks interval between the administrations of both versions was the same for all the participants. This interval, including holidays (Christmas or Easter holidays), was judged large enough to prevent the participants from remembering the items they saw during the first round.

8.3.5 The population and the selection procedure

For the experimental part, we selected participants with moderate ID from 2 special institutions in the area of Geneva, composing the "intellectual disability group" (N = 26): SGIPA (N = 13) and Fondation Ensemble (N = 13). We asked both these institutions to give us the names of volunteer students, which had moderate ID according to their personal files (assessed by IQ tests). The ages of the students varied from 15 to 18 years, the mean age being 16;5 for the SGIPA and 17;0 for the Fondation Ensemble.

First of all, we administered the first 8 items of the CAM-R to the students, in order to know if they could understand the task demands. Following these 8 items, the Raven CPM was administered. Thirdly, STM and WM tasks (from Lanfranchi *et al.*, 2004) were administered, which resulted in 2 more scores. Table 8.3 presents the results of the Raven CPM (raw scores), the STM tasks, and the WM tasks.

Table 8.3
Means and standard deviations for Raven CPM (raw scores) and memory scores for ID participants

	Raven CPM [1] (max. 36 points)		STM tasks (max. 48 points)		WM tasks (max. 16 points)	
	N	*M* (sd)	*N*	*M* (sd)	*N*	*M* (sd)
Fondation Ensemble	13	$14.08\ (3.84)_a$	13	$13.31\ (8.43)_a$	13	$2.85\ (2.61)_a$
SGIPA	13	$23.69\ (5.66)_b$	13	$28.23\ (9.69)_b$	13	$7.62\ (4.74)_b$
$F(5,25)$		13.171		9.479		2.827
p		< .01		< .01		< .05
η^2		.56		.48		.21

[1]: the raw scores of the Raven CPM were used.

Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

The ANOVA with regard to the 3 scores revealed differences between Fondation Ensemble and SGIPA that were very significant. SGIPA clearly got better performances than Fondation Ensemble. For this reason, it was decided to keep the participants apart form each other than to put them together in a single group. Despite the fact that we asked for students with moderate ID, we were forced to recognize that only half of them really had this degree of deficiency, whereas the other half had more a mild ID. As both degrees represent different memory abilities and different capacities, we decided to keep the students of the Fondation Ensemble in order to prove the memory overload hypothesis thar we mentioned in the introduction, and to keep the students of the SGIPA in order to observe the limits of this hypothesis. SGIPA was called ID-high (i.e. high mental age) and Fondation Ensemble was called ID-low (i.e. low mental age).

As we wanted to compare the performanes of the ID participants with those of typically developing children of the same mental age, we selected one typically developing group composed of children without ID between 4 and 8 years old (N = 32; M CA = 6.2). These children came from 4 schools in Geneva and were separated according to their grade level: pre-kindergarten (CA: 4-5 years), kindergarten (CA: 5-6 years), 1st grade (CA: 6-7 years), and 2nd grade (CA: 7-8 years). All had French as their mother tongue. The school teachers were asked to give us names of children that were achieving in the average range at school and who would be interested in participating in our research. The typically developing children first received the first 8 items of the CAM-R. The CPM and the memory tasks were administered to them as well. Table 8.4 presents their results with regard to the Raven CPM (raw scores), the STM tasks, and the WM tasks.

Table 8.4
Means and standard deviation for Raven CPM (raw scores) and memory scores for each class

	Raven CPM[1] (max. 36 points)		STM tasks (max.48 points)		WM tasks (max. 16 points)	
	N	*M* (sd)	*N*	*M* (sd)	*N*	*M* (sd)
Pre-Kindergarten	10	16.00 (2.54)$_a$	10	21.70 (4.83)$_a$	10	3.20 (1.07)$_a$
Kindergarten	8	18.38 (2.88)$_a$	8	24.25 (3.69)$_a$	8	4.75 (5.04)$_a$
1st grade	8	23.88 (6.01)$_b$	8	30.00 (8.49)$_b$	8	4.25 (3.45)$_a$
2nd grade	6	27.50 (3.83)$_b$	6	34.00 (5.09)$_b$	6	7.50 (4.64)$_b$
$F(5,31)$		13.171		9.479		2.827
p		< .01		< .01		< .05
η^2		.56		.48		.21

[1]: the raw scores of the Raven CPM were used.

Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

The ANOVA revealed significant differences between all the classes in the 3 tests. We noticed that the scores in the WM tasks were quite low compared with the scores at the Raven CPM and at the STM tasks. Only children of the 2nd grade got almost half of the points.

According to the 3 tests results, 2 types of groups emerged: one composed of the pre-kindergarten and kindergarten, and the other composed of the 1st and 2nd grade (except for WM tasks, where only 2nd grade was significantly different from the others classes).

According to the raw scores of the Raven CPM, we defined the participants' mental age, which was the age at which the mean percentile score was equal to their raw score (Raven *et al*., 1990). Table 8.5 presents the raw scores (means) for each class, the percentile scores (means) and the mean mental age.

Table 8.5
Means for raw scores (CPM), percentile scores (CPM) and mental age for each class

	N	*M* Raw score	*M* Percentile score	Mental age
Pre-Kindergarten	10	16.00	66.75	4 - 4 ½
Kindergarten	8	18.38	31.40	5 ½ - 6
1st grade	8	23.88	50.25	7 – 7 ½
2nd grade	6	27.50	66.83	7 ½ - 8

According to Table 8.5, 2 distinct groups emerged: one with a mental age between 4 and 6 and another between 7 and 8. Following these results, we used a matching procedure based on the participants' mental age (obtained through Raven CPM)[11] and also on the memory scores (obtained at the STM and WM tasks).

Generally, and based on the results presented in Tables 8.3 and 8.4, ID1 received scores comparable to 1st and 2nd grade, who had a common mental age of 7-8. As for ID2, it received scores comparable to Pre-Kindergarten and Kindergarten children, who had a common mental age of 4-6. By considering the differences between the 4 classes, it was considered a better choice to divide the children into 2 typically developing (TD) groups, as it was the case for the ID participants. TD-low (i.e. low mental age) was composed of the Pre-

[11] The mental age for the Fondation Ensemble and the SGIPA was not computed because the normative data of the CPM were available only for children between 4 and 11 ½ years old.

Kindergarten and Kindergarten children, and TD-high (i.e. high mental age) was composed of the 1st and 2nd grade children. Table 8.6 below indicates number, percentage, chronological age (CA), and mental age (MA) for all participants in their respective group.

Table 8.6
Number, percentage, chronological age (CA), and mental age (MA) for each group

	N	Percentage	M_{CA} (sd)	CA min	CA max	M_{MA} (sd)
TD-low	18	31.0	5;3 (6.07)	4;6	6;3	5;07 (.81)
TD-high	14	24.2	7;3 (8.68)	6;5	8;3	7;8 (1.64)
ID-low	13	22.4	17;1 (9.67)	15;7	18;2	7;6 (1.76)
ID-high	13	22.4	16;5 (11.80)	15;3	18;1	5;0 (1.00)

CA = means and standard deviation at pretest

9. RESULTS

9.1 INTRODUCTION

SPSS for Windows (Version 17.0) was used for the statistical analyses. We used different statistical tests. If they were significant ($p < .05$), we observed the effect size and performed a post-hoc analysis, in order to observe the results in more details.

The following analyses did not take into account the first 8 items of the CAM-R, because they were not counted in the final scores. They were created in order to familiarize participants with the material (touch screen) and with the task demands, which was to reason by analogy. These items were used for training and not for evaluation.

Through our different hypotheses, we expect that all our participants will obtain better performances in the construction version of the CAM-R compared to the classic version. We also expect that our ID participants will overtake the limits of their memory span due to the external memories. Generally, we expected that our attractive device (i.e., touch screen and familiar pictures) would provide more favorable conditions for all the participants in order to obtain good performances in AR.

The following abbreviations will be used throughout the analyses: TD for typically developing group; ID for groups with intellectual disability; and the above-mentioned abbreviations, such as AR (analogical reasoning), and WM (working memory).

9.2 MEMORY AND PERFORMANCE IN ANALOGICAL REASONING

Regarding our first research question, we wanted to know how memory and AR were linked depending on both versions of the CAM-R. Our first research question was the following: In which proportion do WM, STM and Raven CPM determine performance in both versions of the CAM-R in participants with ID and in typically developing children? Instead of computing correlations between the Raven CPM scores and the memory scores for all the participants, we decided to observe the correlations according to TD participants and ID participants in order to know which predictor was the most linked to the success in both versions of the CAM-R.

Three predictors were selected (total raw scores at the Raven CPM, at the STM and at the WM Tasks). Table 9.1 presents the correlations (Pearson) between the pre-tests, the construction version and the classic version according to the participants' scores, depending if they had an ID or not.

Table 9.1
Correlations (Pearson) between pre-tests, construction and classic version scores according to TD participants / ID participants

TD (N = 32) / *ID (N = 26)*	Total Raven CPM	Total WM tasks	Total STM tasks	Total CO	Total CL
Total Raven CPM	1/*1*	.30/*.50***	.68**/*.79***	.64**/*.60***	.55**/*.76***
Total WM tasks		1/*1*	.56**/*.78***	.35/*.51***	.32/*.55***
Total STM tasks			1/*1*	.48**/*.63***	.49**/*.81***
Total CO				1/*1*	.65**/*.73***
Total CL					1/*1*

**All correlations are significant at the level *p* = .01 (2-tailed).

CO= Construction version; CL = Classic version

The table 9.1 displayed Pearson correlation coefficients, and the significance of each correlation coefficient. All the correlations were positive but some were not significant at *p* = .01. The analysis of the table 9.1 allowed the following observations. First of all, the data revealed that scores obtained at the Raven CPM were significantly related to the scores obtained at the construction and classic versions for all the participants.

Secondly, there were significant, but not strong, correlations between the scores obtained at the WM tasks and those obtained at the construction and classic versions but only for the ID participants. These variables did not correlate significantly for the TD participants.

Thirdly, there was a significant correlation between the scores obtained at the STM tasks and those obtained at the construction and classic versions of the CAM-R for all the participants. These correlations were stronger for the ID participants.

In addition, we supposed that memory would less contribute to the participants' performance in the construction version than in the classic version, as the construction version comprised external memories. For both groups, the correlations regarding WM and STM were stronger in the classic version than in the construction version, which confirmed our hypothesis.

In order to know which predictor determined the most the participants' success in both versions of the CAM-R, we computed a multiple linear regression analyze (STEPWISE method) presented in Table 9.2. We computed this analysis by taking into account all the participants together, otherwise this analysis would have been too weak with 2 groups.

Table 9.2
Multiple linear regression for Raven, STM and WM scores (IV) according to both versions (DV)**

	Standardized Coefficients					
	Beta		*t*		Sig.	
	CO	CL	CO	CL	CO	CL
CPM	.55	.39	5.86	2.41	.000	< .05
WM	.21	-.024	1.90	-.205	NS	NS
STM	.18	.54	1.15	3.46	NS	< .01

*IV = Independent Variable; DV = Dependent Variable

CO = Construction version; CL = Classic version.

TD = typically developing children (*N* = 32); ID = students with ID (*N* = 26)

For the construction version, the multiple linear regression indicated that only the Raven CPM was a significant predictor of success for all the participants ($F(1,56) = 20.223$, *MSE* = 407.786, $p < .01$) by predicting 40% ($R^2 = .403$) of the variance. The WM tasks were not a significant predictor of AR performance.

For the classic version, the Raven CPM and the STM were significant predictors of success for all the participants ($F(1,56) = 13.067$, $MSE = 407.244$, $p < .01$). The Raven CPM predicted 30% ($R^2 = .303$) of the variance, and the STM predicted 65% ($R^2 = .655$) of the variance. The WM tasks were not a significant predictor of AR performance.

9.3 VALIDITY OF THE CAM-R

Regarding our second research question, we wanted to assess the validity of the CAM-R. We also wanted to know how the link between the empirical difficulty of the items and the levels of complexity was expressed, in terms of number of relations and time spent for solving the items.

In our second hypothesis, we postulated a positive correlation between the construction version and the classic version because both versions measured AR. We computed correlations (Pearson), which were positive at $p = .05$. The data confirmed our hypothesis: for all groups, the scores obtained at one version were significantly related to the scores obtained at the other, except for ID-high. For TD-low: $r = .47$, $p < .05$; for TD-high: $r = .63$, $p < .05$; for ID-low: $r = .65$, $p < .05$. However, the variables did not correlate significantly for ID-high: $r = .45$, p = NS, which revealed that the success in one version did not influence the success in the other.

We also wanted to measure the concurrent validity of the CAM-R by computing correlations between each version and the Raven CPM, since they measured AR. The data confirmed the concurrent validity of our test, because the correlations were positive between the construction version and the Raven CPM ($r = .62$, $p < .01$), and also between the classic version and the Raven CPM ($r = .67$, $p < .01$).

In our third hypothesis, we postulated that the likelihood to succeed one item of one level of difficulty would be higher than to succeed one item of the level above because there was always one more relation to consider at each level. In order to test this hypothesis, we determined the success percentage of each group according to each level in both versions. To determine the success percentage, we used the mean scores obtained in each level and we divided them with the maximum of possible points for each level. For example, in the first level, the maximum of possible points was 8 and TD-low obtained a mean score of 7.39, which gave an empirical difficulty of 92%. Table 9.3 presents the total number of points for each group in each level and in both versions, as well as the success percentage.

Table 9.3

Means scores and success percentage for each group in each level and in both versions

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (%)	M (%)	M (%)	M (%)
CO 1st level (max points = 8)	7.39 (92%)	8 (100%)	8 (100%)	6.85 (86%)
CO 2nd level (max points = 12)	10.44 (87%)	11.57 (96%)	11.38 (95%)	10.23 (85%)
CO 3rd level (max points = 16)	13.94 (87%)	15.71 (98%)	14.77 (92%)	13.23 (83%)
CO 4th level (max points = 20)	15.5 (78%)	18.57 (93%)	18.54 (93%)	15.62 (78%)
CL 1st level (max points = 8)	7.56 (94%)	8 (100%)	7.85 (98%)	6.46 (81%)
CL 2nd level (max points = 12)	10.28 (86%)	11.79 (98%)	11.23 (94%)	9.92 (83%)
CL 3rd level (max points = 16)	13.78 (86%)	15.57 (97%)	15.0 (94%)	11.69 (73%)
CL 4th level (max points = 20)	15.56 (78%)	18.5 (93%)	17.46 (87%)	12.15 (61%)

CO = Construction version; CL = Classic version

TD-low = Pre-Kindergarten & Kindergarten (MA: 4-6); TD-high = 1st & 2nd grade (MA: 7-8); ID-high = MA: 7-8; ID-low = MA:4-6.

Considering the high percentages, we observed a ceiling effect[12] in both versions, for nearly all TD-high (between 93% and 100%) and for ID-high (between 87% and 100%). Unsurprisingly, the children with the highest mental age got more points.

The scores took into account the increase of the score potential. As the test progressed, the percentage of each group decreased in both versions (except for TD-high that remained

[12] This ceiling effect will be treated differently in the next analyses.

very high because of the ceiling effect). In other words, there was a negative relation between the levels of difficulty and the mean scores. This gave an overall view of the correspondence between empirical and theoretical difficulty of the test items and confirmed our third hypothesis: the success percentage decreased when the complexity level increased. Nevertheless, the effect of complexity was rather modest.

Finally, our fourth hypothesis stated that, in both versions, the time needed to solve the items would increase from one complexity level to the next. We expected to find a linear association between time and level of complexity in each of the groups because we assumed that all participants would increase the time spent for solving the task when the task became more complex. Table 9.4 indicates the total time spent by all groups in each level and in both versions (the time spent in each level will be given in details in Table 9.9).

Table 9.4
Means and standard deviations of the total time spent in each level and in both versions for all the participants

	CO 1st level	CO 2nd level	CO 3rd level	CO 4th level	CL 1st level	CL 2nd level	CL 3rd level	CL 4th level
	M (sd)	*M* (sd)	*M* (sd)	*M* (sd)	*M* (sd)	*M* (sd)	*M* (sd)	*M* (sd)
Total*	16.08 (7.66)	25.19 (10.06)	35.41 (14.33)	46.99 (16.26)	11.91 (6.52)	15.53 (8.53)	19.09 (14.41)	19.86 (8.71)

*Time in seconds

CO = Construction version; CL = Classic version

A repeated multivariate analysis of variance (levels as within-subject factor) × (versions as between-subject factor) was computed. The results showed that there were an effect of the level (F(2.045, 116.59) = 133.141, MSE = 24548.585, $p < .01$, $\eta^2 = .70$), and an effect of the version (F(1,57) = 65.291, MSE = 4566.55, $p < .01$, $\eta^2 = .53$). We also found an interaction effect between the levels and the versions (F(2.658, 151.479)[13] = 13.178, MSE = 802.447, p < .01, η^2 = .19).

Trend analyses (polynomial contrasts) showed a linear trend for the construction version (F(3,54) = 2.155, MSE = 71.935, p < .01, η^2= .82), and for the classic version (F(3,54) = 5.687, MSE = 261.067, p < .01, η^2= .240). Neither quadratic nor cubic effects were significant in both versions, which confirmed the supremacy of the linear trend. On the basis of these results, our fourth hypothesis was confirmed. In addition, we noticed a progression of approximately 10 seconds between each level in the construction version, whereas this progression consisted of approximately 4 seconds between the first 3 levels in the classic version. Moreover, the same time was spent between the 3rd and the 4th levels, which could indicate saturation from the participants due to the difficulty of the version.

9.4 TEST VERSIONS

Regarding our third research question, we wanted to know how the type of versions affected the AR performances of our participants, depending if they had an ID or not, in terms of use of external memories, number of help and time spent for solving the analogies.

9.4.1 Scores depending on the versions

In the first part of our fifth hypothesis, we postulated that all groups would obtain better performances in the construction version than in the classic version, because of the external memories provided. Table 9.5 shows the results for each group according to both versions.

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[13] Mauchly test determined that the assumption of sphericity was violated, both for the levels effect (ϵ = .682, $\chi^2(5)$ = 47.141, p < .01) and for the interaction levels × versions (ϵ = .886, $\chi^2(5)$ = 22.137, p < .01). Therefore degrees of freedom were corrected using Huynh-Feldt.

Table 9.5

Means and standard deviations for the scores concerning each group in both versions (min = 0; max = 56)

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)	TOTAL (N = 58)
	M (sd)	M (sd)	M (sd)	M (sd)	M (sd)
CO	47.17_a	53.86_b	52.92_b	46.23_a	49.86
	(5.64)	(3.04)	(4.43)	(4.89)	(5.66)
CL	47.17_a	54.00_b	$51.54_{a,b}$	40.38_c	48.28
	(7.15)	(2.86)	(5.77)	(6.08)	(7.55)

CO = Construction version; CL = Classic version

Note: Means sharing a subscript in common were not significantly different from each other in both row- and column-wise comparisons (Tukey test).

A mixed 2 (version as within-subject factor) × 4 (groups as between-subject factor) multivariate analysis of variance with repeated measures was performed. The data revealed a significant effect of the version ($F(1,54) = 6.481$, $MSE = 89.446$, $p < .05$, $\eta^2 = .11$). We also found a significant interaction effect versions × groups ($F(3,54) = 3.908$, $MSE = 53.931$, $p < .05$, $\eta^2 =.18$). Firstly, this meant that there were scores differences according to test version and secondly, that the range of these differences varied according to group members.

Then we performed an ANOVA for the construcion version ($F(3,54) = 9.864$, $MSE = 215.817$, $p < .01$, $\eta^2 = .354$), and for the classic version ($F(3,54) = 14.156$, $MSE = 476.260$, $p < .01$, $\eta^2 = .440$). Post hoc comparisons using Tukey B[14] revealed no significant differences between the versions for TD-low, TD-high, and ID-high. However, individuals in ID-low showed a significant difference between the versions by getting better performances in the construction version (M = 46.23) than in the classic version (M = 40.38). Our hypothesis was therefore confirmed only for ID-low.

Regarding the second part of our fifth hypothesis, we assumed that, in the construction version, participants with ID would get scores close to children of the same mental age, on

[14] As the TD participants were in greater number than the ID participants, we checked our results with the Gabriel test (for unbalanced design), which gave the same results.

account of the external memories. Post hoc comparisons using Tukey B revealed no significant differences in the construction version between the performances of ID-low and TD-low (ID-low = 46.23 compared to TD-low = 47.17). No significant differences were found between ID-high and TD-high (ID-high = 52.92 compared to TD-high = 53.86). Regarding the classic version, there were significant differences between the groups. The performances of ID-high were comparable to the performances of TD-high, but were also comparable to the performances of TD-low. However, the performances of ID-low were no longer comparable to the performances of TD-low, as it was the case in the construction version. Our hypothesis was confirmed only in the construction version, supposedly, as a result of having the external memories.

Nevertheless, we noticed an important ceiling effect in TD-high and ID-high. This ceiling effect could be due to our scoring procedure. As said earlier, we decided to attribute 1 point for each correct relation, which brought the maximum number of points to fifty-six to correlate with the total number of relations. But if we have changed the scoring procedure, which was to give 1 point for one item being entirely correct and 0 point for one that was not entirely correct, perhaps the results would also have changed. In order to test this new scoring procedure, we computed the mean number of items that were entirely correct at the first trial (i.e., without the help). Table 9.6 indicates this mean numbers.

Table 9.6
Means and standard deviations for items entirely correct at the first trial (min = 0; max = 16) for each group in both versions

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
CO-correct (1 point)	5.83 $(3.73)_a$	10.89 $(2.37)_b$	8.46 $(3.82)_b$	3.38 $(1.81)_c$
CL-correct (1 point)	6.61 $(3.79)_a$	11.57 $(3.23)_b$	10.38 $(4.89)_b$	3.54 $(1.33)_c$
t	1.22	1.34	2.89	0.29
p	NS	NS	< .05	NS

CO = Construction version; CL = Classic version

Note: Means sharing a subscript in common were not significantly different from each other in row-wise comparisons (Tukey test).

T-tests (paired samples) showed no significant differences between the construction and the classic versions for TD-low, TD-high and ID-low. The differences were significant for ID-high, which got more points in the classic version. The new scoring procedure did not allow promoting the advantages of the external memories, as no group got better scores in the construction version compared with the classic version. However, the ceiling effect found in the previous table was erased, even though TD-high was still the best group and made only a few mistakes. It seemed that both scoring procedures had advantages and disadvantages.

9.4.2 Help depending on intellectual disability

Regarding the first part of our sixth hypothesis, we assumed that participants with ID would need more help than TD children in both versions. Table 9.7 presents the mean number of help for all the groups in both versions.

Table 9.7

Means and standard deviations for the number of help with regard to all groups in each version (min = 0; max = 32)

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
CO	10.11 (3.82)$_a$	4.94 (2.44)$_b$	7.62 (3.75)$_b$	12.85 (1.77)$_c$
CL	9.50 (3.98)$_a$	3.72 (3.14)$_b$	5.62 (4.89)$_b$	12.31 (1.03)$_c$

CO = Construction version; CL = Classic version

Note: Means sharing a subscript in common were not significantly different from each other in row-wise comparisons (Tukey test).

One help was given to all the participants who did not succeed an item completely. A mixed 2 (version as within-subject factor) × 4 (groups as between-subject factor) multivariate analysis of variance with repeated measures was performed. The data revealed significant differences between the groups in the mean number of help in the construction version ($F(3,54) = 2.897$, $MSE = 3.163$, $p < .05$, $\eta^2 = .888$), and also in the classic version ($F(3,54) = 5.327$, $MSE = 9.204$, $p < .01$, $\eta^2 = .475$). Post-hoc analyses confirmed partly our hypothesis: ID-low needed more help than any of the other 3 groups in both versions, whereas ID-high needed approximately the same amount of help than TD-high (the differences being not statistically significant).

Regarding the second part of our sixth hypothesis, we assumed that each group would require more help in the classic version than in the construction version. We computed the success percentage of each group in both trials according to the number of successful relations. For example, in the construction version, TD-low obtained 66% of success at the first trial and 83% at the second trial. This means that the help received between the first and the second trial allowed this group to increase up to 17% of improvement, which corresponded to the gain.

The Table 9.8 below indicates the mean percentage of points at the first trial (without any help) and at the second trial (after receiving the help). This table also indicates the mean number of help received by each group, as in the previous table, in order to value the gain obtained due to the number of help. Finally, this table indicates the gain across the first and the second trial for each group in both versions.

Table 9.8

Mean percentage of points (min = 0; max = 100) for all groups obtained in each version, mean number of help for all groups in each version (min = 0; max = 32), and percentage of gain

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
CO-1st trial	66%	87.5%	79%	57%
CO-2nd trial	83%	97.5%	94%	82%
Number of help	10.11 (3.82)	5.57 (2.34)	7.62 (3.75)	12.85 (1.77)
Gain	17%	10%	15%	25%
CL-1st trial	65%	85%	81%	53%
CL-2nd trial	84%	95%	91%	72%
Number of help	9.50 (3.99)	4.36 (3.25)	5.62 (4.89)	12.31 (1.03)
Gain	19%	10%	10%	19%

CO = Construction version; CL = Classic version

T-tests (paired samples) indicated no significant differences in the mean number of help between both versions for TD-low ($t(17) = .975$, $p <$ NS), for TD-high ($t(13) = 1.319$, $p <$ NS), and for ID-low ($t(12) = .959$, $p <$ NS). However, the differences were significant for ID-high, which needed more help in the construction version than in the classic version ($t(12) = 2.904$, $p < .05$). These results did not confirm the second part of our sixth hypothesis.

Regarding the gain across the first and the second trial, ID-low obtained the highest gain in both versions (neck and neck with TD-low in the classic version only) and TD-high obtained the lowest gain in both versions (neck and neck with ID-high in the classic version). These results were consistent with the results obtained in Table 9.5, and demonstrated that the help allowed the groups with the lowest mental age to get percentages of success close to the groups with the highest mental age.

9.4.3 Time depending on the versions

For our seventh hypothesis, we first postulated that, in each level (each version was composed of 4 levels), participants with ID would need more time to solve the items than the TD children. Table 9.9 shows the means and standard deviations of time spent at each level in the construction version for all groups, and Table 9.10 presents the same information in the classic version. The time is expressed in seconds and represents the mean time spent per item.

Table 9.9
Means and standard deviations of time spent at each level for all groups in the construction version

	CO-1st level *M* (sd)	CO-2nd level *M* (sd)	CO-3rd level *M* (sd)	CO-4th level *M* (sd)
TD-low (N = 18)	14.14 (6.24)$_a$	23.59 (7.9)	34.00 (12.41)	44.66 (12.48)
TD-high (N = 14)	12.33 (3.94)$_a$	22.04 (5.95)	31.45 (8.32)	48.36 (17.34)
ID-high (N = 13)	16.44 (8.92)$_{a,b}$	29.58 (15.34)	35.74 (19.17)	46.42 (16.37)
ID-low (N = 13)	22.42 (7.86)$_b$	26.43 (8.98)	41.29 (15.99)	49.29 (20.61)

Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

CO = Construction version; CL = Classic version

Table 9.10
Means and standard deviations of time spent for all groups in the classic version

	CL-1st level *M* (sd)	CL-2nd level *M* (sd)	CL-3rd level *M* (sd)	CL-4th level *M* (sd)
TD-low (N = 18)	9.92 (4.14)$_{a,b}$	13.01 (7.78)$_a$	19.95 (22.97)	18.44 (9.17)
TD-high (N = 14)	7.07 (3.18)$_a$	11.29 (4.69)$_a$	14.51 (6.59)	21.46 (11.42)
ID-high (N = 13)	13.41 (5.76)$_b$	20.58 (7.93)$_b$	22.08 (9.15)	22.21 (7.65)
ID-low (N = 13)	18.38 (7.24)$_c$	18.56 (10.23)$_{a,b}$	19.85 (8.48)	17.77 (4.96)

Note: Means sharing a subscript in common were not significantly different from each other in column-wise comparisons (Tukey test).

CO = Construction version; CL = Classic version

A mixed 4 (levels as within-subject factor) × 2 (version as within-subject factor) × 4 (groups as between-subject factor) multivariate analysis of variance with repeated measures was performed. The data showed an effect of the levels (F(2.103, 113.586) = 129.287, MSE = 23400.322, $p < .01$, $\eta^2 = .71$), and an effect of the version (F(1,54) = 74.902, MSE = 4515.90, $p < .01$, $\eta^2 = .58$). We also found several interaction effects: an interaction effect level × group (F(6.31, 113.586) = 0.822, MSE = 148.696, p = NS), which was not statistically significant; an interaction effect version × group (F(3,54) = 4.041, MSE`= 243.633, $p < .05$, $\eta^2 = .18$); an interaction effect level × version (F(2.815, 152.028) = 12.487, MSE = 807.873, $p < .01$, η^2 = .19); and an interaction effect level × version × group (F(7.598, 152.028)[15] = 0.764, MSE = 49.429, p = NS), which was not statistically significant.

Post-hoc analyses revealed that our hypothesis was partially confirmed. In the construction version, ID-low was only comparable to ID-high. That group spent more time than both TD groups but only at the 1st level. As for the classic version, ID-low was not comparable to any of the other 3 groups because it clearly spent more time than these groups at the 1st level. However, at the 2nd level, ID-low was only comparable to ID-high. Finally, there were no significant differences between the groups at the 3rd and 4th levels.

Regarding only the TD children, we expected that the young children (i.e. TD-low) would spend more time than the older children (i.e. TD-high). This was not confirmed because both groups showed no significant differences in all levels and in both versions.

The second part of our seventh hypothesis postulated that the items of the construction version would need more time to be solved than the items of the classic version. Table 9.11 presents the Total time spent in each level and in each version for all the participants.

[15] Mauchly test determined that the assumption of sphericity was violated, both for the levels effect (ϵ = .701, $\chi^2(5) = 47.218$, $p < .01$) and for the interaction level × version (ϵ =.938, χ^2 (5) = 20.750, $p < .01$). Therefore degrees of freedom were corrected using Huynh-Feldt.

Table 9.11

Total time spent in each level and in each version for all the participants

	1st level	2nd level	3rd level	4th level
	M (sd)	*M* (sd)	*M* (sd)	*M* (sd)
CO	16.08* (7.66)	25.19 (10.06)	35.41 (14.33)	46.99 (16.26)
CL	11.91 (6.52)	15.53 (8.53)	19.09 (14.41)	19.86 (8.71)
t	4.632	6.528	6.675	14.033
p	< .01	< .01	< .01	< .01

*Time in seconds

CO = Construction version; CL = Classic version

The t-test (paired samples) regarding the Total Time of each version revealed significant differences between both versions for all groups ($p < .01$). All groups clearly spent more time for solving the analogies in the construction version than in the classic version, which confirmed the second part of our hypothesis. These data corroborated those found in Table 9.4, in which more time was spent in the construction version by all the participants.

9.5 TYPE OF REASONING

Regarding our fourth research question, we wanted to know in what extent the familiarity of attributes and relations and the type of relations influence the AR performances of our participants?

9.5.1 Reasoning by analogy or by association?

Our eighth hypothesis postulated that the majority of our participants would reason by analogy and not by association because our analogies were composed of familiar attributes and relations. Table 9.10 presents the average percentage of answers performed by association for all groups in each version.

Table 9.12
Means and standard deviations for the number of associations according to all groups in both versions

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
CO	1.06 (2.01)	0	.23 (.59)	1.23 (1.79)
CL	2.11 (1.88)	.21 (.58)	.54 (.97)	2.38 (2.14)
t	2.54	1.39	1.00	1.89
p	< .05	NS	NS	NS

CO = construction version; CL = classic version

In each version, 23 associations were presented. The mean numbers were meaningful and spoke for themselves because participants selected between 0 and 2.38 associations in both versions on a total of 23. We can observe that TD-high and ID-high, which were the 2 groups with the highest MA, chose fewer associations than the other 2 groups in both versions. These results confirmed our hypothesis because just a few associations were selected.

Although the difference of selected associations between both versions did not take part in our hypothesis, we observed if it was the case. T-tests (paired samples) showed significant differences only for TD-low in the mean number of selected associations between both versions ($t(57) = 2.54$; $p < .05$). This group chose more associations in the classic version than in the construction version. For the other 3 groups, no significant differences were found.

9.5.2 Conceptual vs. Perceptual relations

Our ninth hypothesis postulated that in both versions, all groups would have more success with the perceptual items than the conceptual items. Table 9.11 shows means and standard deviation concerning the number of points for each group with regard to perceptual and conceptual items in the construction version, and Table 9.12 indicates the same data in the classic version.

Table 9.13

Means and standard deviations concerning the number of points for each group with regard to perceptual and conceptual items in the construction version (max. = 28 pts)

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
Conceptual	22.94 (4.15)	27.14 (1.35)	26.54 (2.90)	21.92 (4.03)
Perceptual	24.22 (2.34)	26.71 (1.82)	26.38 (2.18)	24.31 (2.21)
t	1.47	1.58	.21	2.00
p	NS	NS	NS	NS

Table 9.14

Means and standard deviations concerning the number of points for each group with regard to perceptual and conceptual items in the classic version (max. = 28 pts)

	TD-low (N = 18)	TD-high (N = 14)	ID-high (N = 13)	ID-low (N = 13)
	M (sd)	M (sd)	M (sd)	M (sd)
Conceptual	24.11 (4.24)	27.15 (1.99)	26.69 (2.18)	18.77 (4.13)
Perceptual	23.06 (3.95)	26.69 (1.70)	24.85 (3.76)	21.62 (4.72)
t	1.12	.73	3.15	1.59
p	NS	NS	$< .01$	NS

T-tests (paired samples) showed no significant differences between the perceptual and the conceptual items for any group, except for ID-high in the classic version, where the conceptual items were better succeeded than the conceptual items. For the other 3 groups, no significant differences were found between perceptual and conceptual items. With the same 3 groups, we could again observe a ceiling effect because they received between 23 and 27 points out of 28 points. Only ID-low did not succeed as well as the other three groups.

In order to perform a finer analysis of the perceptual and conceptual relations, we propose one figure, which present the number of successful relations for each category in both versions. Each relation was not presented the same number of times. For instance, color was presented 8 times on the 8 perceptual items, but shape was only presented 6 times. For this reason, we computed percentage of the number of relations on the total number of relations. Figure 9.1 below presents our results for the perceptual and conceptual relations in both versions.

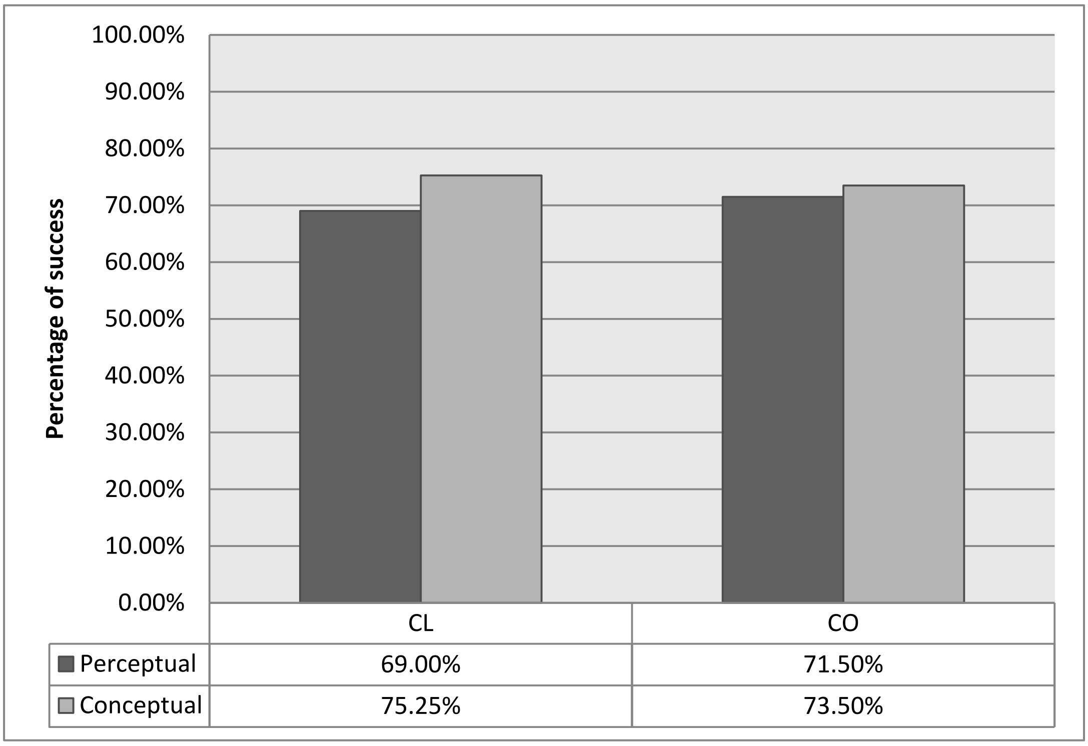

Figure 9.1 Percentage of success with regard to conceptual and perceptual relations

The data in the figure showed higher percentages for the conceptual relations above perceptual relations in both versions. In order to know if this superiority was statistically significant, we performed a T-test (paired samples), which revealed no significant differences between perceptual and conceptual relations neither in the classic version, nor in the construction version.

In more details, we established rankings for perceptual and conceptual relations. In order to discriminate between the relations, we observed 4 perceptual relations: presence, color, size, and shape; and 4 conceptual relations: functional, weather, human, and type of object.

With regard to the classic version, the “human” relation (79%) was the most successful conceptual relation, and “color” (75%) was the most successful perceptual relation; “weather” was the least successful conceptual relation (69%), and “size” was the least successful perceptual relation (66%).

For the construction version, the “color” (81%) was the most successful perceptual relation, and “type of object” was (78%) was the most successful conceptual relation; “human” was the least successful conceptual relation (76%), and “size” was the least successful perceptual relation (65%).

To sum up, these rankings showed that the “color” relation was the most successful perceptual relation in both versions of the CAM-R. The “human” relation, which was the most successful conceptual relation in the classic version, was, in contrast, the least successful conceptual relation in the construction version.

In this latest hypothesis, we also wanted to know if there was a developmental progression from perceptual items to conceptual items. Table 9.11 and Table 9.12 showed no significant differences between perceptual and conceptual items in both versions. Gentner’s assumption was not validated by our results.

10. DISCUSSION

10.1 MEMORY AND PERFORMANCE IN ANALOGICAL REASONING

We wanted to know in which proportion WM, STM and Raven CPM determined performance in the CAM-R in participants with ID and in typically developing children. The data revealed quite high correlations between the Raven CPM and the scores obtained at the both versions of the CAM-R for all the participants, which confirmed the postulated link.

The data also revealed quite high correlations between the STM and the scores at the CAM-R for all the participants, and revealed correlations between WM and the scores at the CAM-R only for the ID participants. The postulated link between the memory and both versions of the CAM-R was confirmed with regard to the STM tasks. The success in both versions of the CAM-R was linked to the success at the STM tasks, but more strongly for the ID participants. These results confirmed the work of several researchers, which stated that a strong relationship existed between memory and reasoning (e.g., Cho, Holyoak, & Cannon, 2007; Conway, Cowan, Bunting, Therriault, & Minkoff, 2002; Carpenter, Just, & Shell, 1990; Engle, Tuholski, Laughlin, & Conway, 1999). The same postulated link between the memory and both versions of the CAM-R was confirmed partially to the WM tasks. This was not surprising because all the participants got lower performances in the WM tasks.

In addition, we hypothesized that memory would less contribute to the participants' performance in the construction version than in the classic version, as the construction version comprised external memories. This hypothesis was confirmed because the correlations regarding WM and STM were stronger in the classic version than in the construction version for both groups, which was coherent with our theoretical background: because construction version offloaded the memory, it was logical that memory played a minor role in this version than in the classic version, where the memory was overloaded.

Furthermore, during the pretest, all the participants got better scores in the Raven CPM and in STM tasks than in the WM tasks, in which their performances were quite low. This supremacy of the Raven CPM and STM was confirmed in the multiple linear regression. In the construction version, only the Raven CPM was a significant predictor of AR success in the CAM-R and in the classic version, both Raven CPM and STM were significant predictors. These results meant that the memory played a role in the classic version, in which the participants' memory was supposed overloaded, whereas the memory did not play a role in the construction version, in which their memory was supposed offloaded. The fact that WM was not a predictor of success in the CAM-R could mean that the participants did not use their WM for solving the analogies, perhaps because the amount of information went beyond the capacity of their memory span (e.g., Just & Carpenter, 1992; McConaghy & Kirby, 1987; Shah & Miyake, 1999), or because they did not possess the sufficient knowledge and skills to use their WM (Ericsson & Kintsch, 1995).

10.2 VALIDITY OF THE CAM-R

Regarding our second hypothesis, we postulated a positive correlation between both versions of the CAM-R as they both measured AR, which was confirmed for all groups except for ID1. In other words, the more they succeeded in the construction version, the more they succeeded in the classic version and vice versa.

In addition, we also assessed the concurrent validity of the CAM-R with regard to the Raven CPM. The data revealed positive correlations between each version of the CAM-R and the Raven CPM, but stronger correlations with regard to the classic version. This was not surprising as this version presented the matrices and the solutions (i.e., pictures) in the same format than in the Raven CPM. Moreover, the correlations obtained between each version and the Raven CPM were not so strong as both tests were not similar. For example, the CAM-R proposed hints within the test, but the Raven CPM did not propose any hint, which could indicate the weakness of correlations.

Regarding our third hypothesis, we postulated that the probability to succeed one item of one level of difficulty would be higher than to succeed one item of the level above because there was always one more relation to consider at each level. One of the criticisms made to the first version of the CAM was that the complexity levels did not correspond to the difficulty levels. Therefore, we decided that the number of elements, as well as the number of relations, should grow according to the levels of complexity.

The results confirmed this hypothesis: the scores of our participants increased according to the levels of complexity, but the success percentage decreased. We noticed a ceiling effect in both versions for ID-high and TD-high, the groups with the highest mental age. This ceiling effect was not surprising, as Siegler and Svetina (2002) showed that items containing less than 6 transformations were relatively easy for 8-year-old children. As ID-high and TD-high shared a mental age between 7 and 8 years of age, our results were consistent with Siegler & Svetina's results. Our decision to present items with no more than 5 relations was taken according to our population. We wished to have at our disposal students with moderate ID. Unfortunately, only half of the students had a real moderate ID, the other half had a mild ID. As we designed the CAM-R before the selection of the population, it was too late in our project design for adding more levels of complexity. Moreover, the addition of more levels would also have extended the last of the test, which was already longer than the usual tasks. When we designed the test, we did not know that all the participants would end the test without being boring or tired.

Regarding our fourth hypothesis, we postulated that the time needed to solve the items would increase from one complexity level to the next. The time spent by all the participants between each level within a version was statistically significant, which confirmed our hypothesis. In addition, we found a linear association between the time spent for solving the items and the levels of complexity. When we observed the results more closely (see Table 9.9), we found that all groups behave the same way in the construction version: as the test became more complex, participants needed more time to solve it, which was expected because there was one more relation to consider at each level. These results corroborated those of several authors (e.g., Arendasy & Sommer, 2005; Bethell-Fox *et al.*, 1984; Foorman *et al.*, 1985; Mulholland *et al*., 1980; Sternberg & Rifkin, 1979) by stating that time increased with the number of elements involved in the analogies.

In addition, we noticed a progression of approximately 10 seconds between each level in the construction version, whereas this progression consisted of approximately 4 seconds between the first 3 levels in the classic version. As there were more elements of answer (construction version) than pictures (classic version), the processing time for solving each item was more important in the construction version compared with the classic version. However, in the classic version, the same amount of time was spent in the 3rd and 4th levels, which could indicate a possible saturation due to the complexity of the task.

The 3 hypotheses allowed us to validate the link between the empirical difficulty of the items and their theoretical level of complexity.

10.3 TEST VERSIONS

10.3.1 Scores and intellectual disability

The first part of our fifth hypothesis, which stated that all groups would obtain better scores in the construction version than in the classic version was confirmed only for ID-low, indicating that external memories were beneficial for this group but not for the others. As stated by Büchel (2006), the main problem of individuals with moderate ID was a problem of memory limitation that could be reduced by the use of external memories, which was demonstrated by our results.

TD-high and ID-high obtained quite similar results in both versions (differences being not statistically significant), which was logical considering that they shared the same mental age. These results also showed the limits of the memory overload hypothesis exposed in the introduction. For participants with a mental age between 7 and 8, the test seemed to be too easy and the external memories were not so useful. Both these groups also obtained better results in the memory tasks and on the Raven CPM compared to TD-low and ID-low. However, TD-low, who shared the same mental age as ID-low, obtained similar results in both versions and did not benefit from the external memories.

In sum, ID-low, even if it shared the same Raven CPM performances and the same memory abilities than TD-low in the pretest, showed more problems in performing the analogies. So, the differences indicated difficulties in processes rather than in abilities (Goswami, 1989). The moderate ID participants were able to reason by analogy but proably had more problems to treat several relations at the same time than TD children. It seems that the moderate ID played a crucial role in the performances, more than the mental age. However, the external memories enabled ID-low to receive scores not so distant from the other 3 groups.

In addition, we noticed an important ceiling effect in TD-high and ID-high. We also noticed in both IDG and in TD-low a standard deviation one third higher when compared with the one observed in TD-high, which indicated important inter-individual differences in comparison to the need of external memories. TD-high did not need external memories to obtain good performances. This ceiling effect was erased when we changed the scoring procedure. By giving 1 point for an item entirely correct and 0 point for an item not entirely correct, TD-high and ID-high were still comparable (no significant differences between the scores) but their mean scores were not as high as they were with the previous scoring procedure (i.e., 1 point for each correct relation). The advantage of our first scoring procedure (see Table 9.5) was to promote the reasoning of all the participants. This promotion was not possible with the new scoring procedure (see Table 9.6), because each group got better scores in the classic version than in the construction version. This was not surprising as there were more elements of answer (construction version) than pictures (classic version). Therefore, the possibility to make mistakes was bigger in the construction version than in the classic version. The new scoring procedure induced unevenness between both versions, whereas the first scoring procedure allowed knowing how much relations were treated by each group.

Regarding the second part of our fifth hypothesis, we assumed that, in the construction version, participants with ID would get scores close to children of the same mental age, due to the external memories. As noted earlier in our theoretical part, 2 main positions tended to explain the origin of ID, and the presence or absence of differences between individuals having the same mental age but not the same chronological age. Our results confirmed similar performances in the construction version between TD-low and ID-low (MA: 4-6), and between TD-high and ID-high (MA: 7-8), the differences being not statistically significant. These results inclined toward the developmental position (Hodapp & Zigler, 1997; Hodapp *et al.,* 1998), and indicated the role played by the mental age in the resolution of analogical items.

We noticed again the role played by the ID degree with regard to the level of performances. According to Paour (1991; Büchel & Paour, 2005; Paour & Asselin de Beauville, 1998), this difference of performances could be due to a cognitive low-functioning with a motivational origin. Our test was composed of 2 versions, each lasting 30 minutes. As mentioned earlier, this duration of time represented a long period of sustained attention. According to the teachers and the support workers, normally, daily tasks performed by all our participants did not surpass 10 minutes. Each of our versions represented 3 times the maximal time of attention required by the support workers. In the same manner, this time could represent an over taxing attention requirement for the children with the lowest mental age. As said in the discussion regarding the test version, TD-low and ID-low spent less time in the 4th level than in the 3rd level in the classic version. Nevertheless, each participant reached the end of each version, which could be explained by the attractive device (touch screen) and by the familiarity of the pictures.

10.3.2 Help and intellectual disability

Our fifth hypothesis stated firstly that participants with ID would need more help in both versions than typically developing children. This part of our fifth hypothesis was confirmed only for ID-low who needed more help than any of the other 3 groups in both versions. No significant differences were found between ID-high and TD participants. We noticed again the role played by the ID degree. Even if ID-low and TD-low shared the same mental age, ID-low needed more help for solving the task than the TD children. This was not the case for ID-high, which needed the same amount of help than TD-high. These results were consistent with other studies, which showed that individuals with ID encountered difficulties with AR tasks compared with typically developing individuals because of deficit cognitive functions, such as limitations in WM, lack of comparative behavior, non-use of strategies, deficit of attention, or low motivation (e.g., Agran & Wehmeyer, 2005; Alloway *et al.*, 2009; Büchel, 2007; Halford, 1993; Hulme & Mackenzie, 1992; Lifshitz *et al*., 2005). These deficits might have prevented the participants of ID-low from being successful at the first attempt.

Secondly, we assumed that each group would require more help in the classic version than in the construction version. Our hypothesis was not confirmed because no significant differences were found in the mean number of help between both versions for each group, except ID-high who needed more help in the construction version. Due to the fact that the construction version required more steps than the classic version, ID-high needed more help to succeed all the steps despite the presence of external memories. On one hand, the external memories enabled this group to get better performances in the construction version than in the classic version; on the other hand, this group needed more help because of the numerous elements of answer present in the construction version.

This second part of our fifth hypothesis gave us information about how advantageous the help was for our participants. Each group improved its percentage of success in the second trial, the help being effectively advantageous. However, the 4 groups did not need the same amount of help: TD-low and ID-low needed more help than the other 2 groups, which was logical because they had the lowest mental age, but this help enabled them to get closer to the participants with the highest mental age. Our decision to give a feedback after the first trial (in order to help our participants) had a beneficial effect on their scores.

We also noticed that ID-low was the group who received the fewest points in both versions in comparison to the other 3 groups. Therefore, it was the group who made the biggest progress between the first and the second trials. The consequences of giving the help were bigger for ID-low than for the other 3 groups.

10.3.3 Time and intellectual disability

The first part of our seventh hypothesis was that, in each level, participants with ID would need more time to solve analogical matrices than the typically developing children. Results showed that for levels 3 and 4 in both versions, which were also the most difficult of our test, all groups spent approximately the same amount of time for solving the analogies, the differences being not statistically significant. Our hypothesis was confirmed only for ID-low in levels 1 and 2 in the classic version and only in level 1 in the construction version. In fact, in the most difficult levels, participants with ID performed the same as participants without ID. These results were in contradiction with those of several authors (e.g., Hulme & Mackenzie, 1992; Jensen *et al*., 1981; McConaghy & Kirby, 1987), which stated that children with below average intelligence spent more time solving analogies than children with average intelligence.

In addition, all the participants spent approximately 20 seconds at the maximum in the classic version, whereas they spent between 30 and 40 seconds in the construction version. We could explain these results by contrasting the format of each version. The action to construct the answer part by part could also retain the participants’ attention, whereas the action to choose a picture among several others could be less motivating.

We could explain these results differently: in the classic version, ID-low and ID-high spent approximately the same amount of time at the 4 levels, which indicated saturation due to the cognitive load of analogical items. In other words, they could not spend more time to analyze the items, which explained the more subtle results. In addition, Hulme and Mackenzie (1992) argued that persons with ID had difficulty to concentrate on one object or one task and had greater distractibility than typically developing individuals. We have to keep in mind that each version lasted 30 minutes, which is already twice or three times more than what the participants were used to. This decline in time was not found in the construction version perhaps because the construction modality maintained our participants' attention.

In addition, we also expected that young TD children (i.e., TD-low) would have spent more time for solving the analogies than older TD children (i.e., TD-high). This was not confirmed as no significant differences were found between both groups in all levels and in both versions, which contradicted the results of Foorman *et al*. (1985).

Regarding the second part of our seventh hypothesis, we hypothesized that the items of the construction version would need more time to be solved than the items of the classic version. This second part of our hypothesis was confirmed because we found differences between both versions. The fact that the answer elements of the construction version were in greater numbers than the pictures in the classic version led our participants to spend more time in the construction version. These results corroborated Sternberg and Rifkin's (1979) results, who demonstrated that separable attributes took more time to be considered than integral attributes.

10.4 TYPE OF REASONING

10.4.1 Reasoning by analogy or by association?

Our eighth hypothesis, which stated that the majority of our participants would reason by analogy and not by association because our analogies were made with familiar attributes and relations, was confirmed for both versions. These results corroborated Goswami and Brown's (1989, 1990) results and indicated that when the analogies were composed of familiar elements and relations, they enabled the participants to reason by analogy.

Although the difference of selected associations between both versions did not take part in our hypothesis, we found that all groups selected more associations in the classic version than in the construction one, but the differences were significant only for TD-low. As the classic version of the CAM-R was supposed to overload the memory, all groups reasoned more by association than by analogy because associative reasoning was simpler than AR. In addition, the theory of cognitive load (Paas *et al*., 2003; Sweller, 1988, 1994) explained that if

WM was overloaded, then the learning was disturbed; therefore, there were not any resources available for reasoning by analogy.

10.4.2 Conceptual vs. Perceptual relations

Our ninth hypothesis sought to discover whether or not conceptual items were more difficult to solve than perceptual ones, as stated by Tzuriel (2007; Tzuriel & Galinka, 2000), Carpenter *et al.* (1990), and Gentner (2003; Gentner & Ratterman, 1991). According to Tzuriel (2007), conceptual items required higher-level processes but perceptual items did not. However, according to Piaget *et al.* (1977) and to Klein and Stafford (1978), perceptual analogies were more complex than conceptual analogies. Our results showed no differences between both categories, except for ID-high in the classic version, who succeeded in performing conceptual items better than perceptual ones. In general, our results could neither corroborate Tzuriel's and Carpenter *et al.*'s assumption, nor contradict Piaget's and Klein and Stafford's assumptions. Therefore, our hypothesis was not confirmed. However, our results corroborated Lifshitz *et al.*'s (2011) results, who administered the CCPAM to adolescents and adults with ID and also found no differences between both types of analogies in their study, as both groups demonstrated the same improvement in the perceptual and in the conceptual analogies.

We could explain these results by asserting that the conceptual relations were linked to visual characteristics, that being that the "gender" was represented by a man and a woman, the "action" was represented for instance by a man standing or a man walking, the weather was represented by a sun with clouds or rain with clouds, and the "type of object" was represented by the difference between 2 objects, 2 types of animals, 2 kinds of earth, etc. All these relations used were visually distinguishable, which is usually not the case between 2 concepts, such as "lives in" relation, which required thinking about characteristics absent from the matrix. In addition, our analogies were composed from 2 to 5 relations, whereas the analogies of the CCPAM were only composed of 2 relations. It seemed that analogies composed of more than 2 relations could not be distinguished in terms of conceptual and perceptual relations. At this time, we do not have the possibility to know more about this distinction with numerous relations.

However, our results confirmed the predominance of several relations. According to several authors (e.g., Odom *et al.*, 1975; Siegler and Svetina, 2002; Stevenson *et al.*, 2011), relations such as “color” and “shape” were easier to solve than other relations, such as “size”. In addition, the predominance of color as being the most successful relation was consistent with previous studies (e.g., Alexander *et al*., 1987; Tzuriel & Klein, 1987).

In this last hypothesis, we also wanted to know if there was a developmental progression from perceptual characteristics to conceptual characteristics in TD children, as stated by Gentner (2003; Gentner & Ratterman, 1991). The data showed no significant differences between perceptual and conceptual items in both versions. Young TD children did not consider more perceptual items than older TD children, which did not confirmed Gentner’s assumption.

10.5 GENERAL DISCUSSION

As expected, memory abilities played a crucial role in the classic version and less in the construction version. The pictures of the classic version tended to overload the memory, whereas the separated elements of construction device tended to relieve it. Mental age also played a crucial role in both versions, which led our participants who had the highest mental age (i.e., TD-high and ID-high; MA = 7-8 years old) to get better performances than the participants with the lowest mental age (i.e., TD-low and ID-low; MA = 4-6 years old). Their scores were higher in both versions, they chose associations less often, they needed less help in both versions, and they spent less time for solving the analogies. However, our results strongly indicated that, with the support of external memories, participants with moderate ID (i.e., ID-low) could obtain better performances than without such support, and in addition, were able to reach a similar level of performance as typically developing children of the same mental age.

The construction version of our test may have promoted a more analytical way to solve the analogies. As the answers had to be constructed part by part, the participants could treat one relation after another without remembering the relations already taken into account in a previous choice. Therefore, they focused on one and only one aspect at a time, whereas, in the classic version, they had to focus on an entire picture, with which they had to process the item in its entirety. The consequences were that the construction version with separated elements required more time from all the participants than the classic version. The practical implication of our construction version was that the separation of elements was more beneficial for individuals with moderate ID (i.e., ID-low) and produced better performances. It also enabled these participants to obtain scores that were comparable to those of typically developing children of the same mental age. In addition, the construction version allowed the moderate ID participants to go beyond the limits of their memory span because the version offloaded their memory. The step-by-step analysis of the task made the regulation of the metacognitive control easier because the participants selected one element after another, whereas in the classic version they needed to observe all the elements at the same time. Nevertheless, previous studies showed that metacognitive strategies (anticipation, planning, and control) required many memory resources. This meant that the metacognitive argument represented also a memory argument, as Büchel (2006) postulated it.

In Chapter 8 (Method), we mentioned 3 limitations made against the CAM test. The first limitation concerned the visual aspect of the items, which was improved with the drawings of one single person (Borel, 2008). Concerning the second limitation, the item difficulty, we avoided adding relations in the CAM-R and we put a number of elements, which grew according to the levels of complexity. Our results indicated that the theoretical level of complexity corresponded to the empirical difficulty of our test. Finally, concerning the third limitation, the conceptual and perceptual relations, we decided to separate both kinds of relations distinctively. Each item was composed either by conceptual relations (e.g., cutting, opening, type of objects, etc.) or by perceptual relations (e.g., color, shape, size, etc.). However, our results did not indicate any differences between both types of relations, partly because all relations were linked to visual characteristics.

10.6 LIMITATIONS OF THE STUDY

Several limits of our study needed to be recognized. One limitation concerned the small sample size of our population. Our study only included fifty-eight participants; hence, our results must be interpreted with caution and their generalization is limited.

Secondly, we mentioned several times a ceiling effect for the groups with the highest mental age (i.e., TD-high and ID-high), which indicated that both versions were too easy for these groups. They obtained between 52 points and almost 54 points out of 56 in the construction version, and between 51 and 54 points out of 56 in the classic version. Our test seemed to be too easy for children and ID participants with a mental age of 7 years and beyond. They did not benefit from the external memories because they obtained approximately the same scores in both versions. As stated in the discussion, this ceiling effect was not surprising and confirmed Siegler and Svetina's (2002) assumption, demonstrating that items containing less than 6 transformations were relatively easy for 8-year-olds children.

However, we could also explain our ceiling effect in 2 other ways. First, the ceiling effect was perhaps due to our scoring procedure. We chose to attribute 1 point for each correct relation because we wanted to give value to our participants' reasoning. By changing the scoring procedure (i.e., 1 point for an item entirely correct and 0 point for an item not entirely correct), we avoided this ceiling effect. TD-high was still the best group, but the scores of the 4 groups were more subtle than with the previous scoring procedure. The new procedure allowed us to locate ID-low as the group obtaining the fewest points in both versions. This group was still comparable to TD-low in the construction version, but no longer in the classic version.

In order to avoid the ceiling effect for older children, we propose to add more levels of complexity and hence more relations, which could suit older children. The adding of more difficult levels could be twofold: it can indicate how many relations the groups with the lowest mental age (i.e., TD-low and ID-low) could treat, because they could perhaps treat more than 5 relations; it can also give value to the external memories, which were not very useful with 5 relations to treat at the same time in the construction version.

Our ceiling effect was perhaps due to our feedback procedure. Lifshitz *et al.* (2011) also found a ceiling effect because their participants obtained very high results in perceptual and conceptual analogies. The authors explained this ceiling effect with their mediation procedure. The participants were taught to focus on processes, such as selecting, comparing, and organizing, which proved to be an effective strategy for solving the analogies, and which produced high performances.

Thirdly, we encountered some issues between conceptual and perceptual items. At the beginning of our test, we proposed to separate these categories by stating that conceptual items would be more difficult to solve than the perceptual items, as argued by several authors. However, our results could not confirm our hypothesis partly because all our relations were visually recognizable, which explained the absence of differences between both categories.

Tzuriel and Galinka (2000) used analogies composed of only 1 or 2 relations, which allowed them to design “real” perceptual and conceptual analogies. As our analogies were composed of several relations, from 2 to 5, we actually do not know if it would be possible to improve this limitation. Our main concern was that the conceptual categories could be visually represented in a perceptual way. If we want to make the conceptual analogies more difficult, complex concepts have to be selected. Perhaps, we will not be able to draw these complex concepts so that they would be understood as they should be.

Finally, a fourth limitation concerned the associations present in our test. It was our choice to put for example, a lemon squeezer in association with a lemon or a baby in association with a baby carriage. We did not have time to ask children’s points of view, which would have been more reliable. However, we thought that our choices were as close as possible to theirs. In order to remedy this issue, we created a second version of our test, the CAM-R-revised, in which we asked a hundred children, for their points of view. Sometimes, our choices were the same as theirs; otherwise, we replaced our associations with their choices. For instance, in the flower item (see Figure 8.3), we changed the watering can and the leaves with a vase and a bunch of flowers. The Table 11.1 below presents the associations of each item in the CAM-R version and in the CAM-R-revised version.

Table 10.1

Associations in the CAM-R and in the CAM-R-revised

Item	**Level**	**Association 1 CAM-R**	**Association 2 CAM-R**	**New association 1 CAM-R-revised**	**New association 2 CAM-R-revised**
Ice Cream (P)*	TR*** – 1	Spoon	Ice cream bowl	Lollipop	Crunched ice cream
Flower (P)	TR – 1	Leaves	Watering can	Bunch of flowers	Vase
Lemon (C)**	TR – 1	Lemon squeezer	-	Lemon tree	Orange juice small carton
Candle (C)	TR – 1	Lamp	Match	Lamp	Star
Girl (P)	TR – 2	Table	Jump rope	Purse	Soccer ball
Rabbit (P)	TR – 2	Birdcage	Bunch of carrots	Cage	Crunched carrot

Ladybird (C)	TR – 2	Caterpillar	-	Bee	-
Beach (C)	TR – 2	Plastic duck	-	Boat	-
Pear (P)	1	Half pear	-	Apple	Fruit bowl
Bike (P)	1	Chair	Motorbike	Sun	Motorbike
Swimming Pool (P)	2	Swimsuit	-	Sun umbrella	-
Truck (P)	2	Car	Trailer	Car	-
Mouse (C)	2	Bunch of carrots	-	Rat-trap	-
Snail (P)	3	Caterpillar	Branch	Rock	Wild flowers
Car (P)	3	Motorbike	Backpack	Taxi	Group of suitcases
Umbrella (C)	3	Bus	-	Mountain	-
Clown (P)	4	Balloons	Circus tent	Trumpet	Circus tent
Train (P)	4	Rail	Driver	Rail	Suitcase
Baby carriage (C)	4	Baby	-	Rake	-
Tree (C)	4	Basket	-	Basket	Rake

*P = Perceptual; **C = Conceptual

*** TR = Training

10.7 IMPROVEMENT OF THE ITEMS OF THE CAM-R

10.7.1 Modification of relations

Besides the change of associations, the CAM-R-revised presented an improvement of the items. Nevertheless, the CAM-R-revised was not exposed to a test on the field. Our suggestions in this subchapter are only theoretical. The twenty-four items of the CAM-R-revised are presented in the Appendices, section E.

First of all, we changed some colors so that they were deeper. Secondly, some items were subjected to modifications because we noticed that some relations were represented too often in the entire test, such as the “adult/child” relation or the “sun/moon” relation. For example, the "Window" item, which contained an "adult/child" relation in the CAM-R, was replaced with a "man-woman" relation in the CAM-R-revised (see Appendices, Section E.15). In the same manner, the "Dog" Item changed its name and was replaced by the "Cat" Item, because the bowl was linked more with the dog than with the cat. All the participants did not understand why the cat had the same bowl as the dog (See "Cat" Item in Appendices, Section E.20).

10.7.2 Persistent presence of one element

Some items were still problematic. In some items there was an element, which was present in the *A, B, C* and *D* terms of the matrix, and hence, did not require the participants to reason by analogy. In the "Lemon" Item, the plate was always present in the *A, B, C*, and *D* terms. The same problem occurred with the "Pear" Item, where the leaf always needed to be put. In the "Carrot" Item, the table was always present, as well as in the "Book" Item. In the "Clown" Item, the clown always needed to be put. We modified these items (See "Lemon" Item in Appendices, Section E.3; "Pear" Item in Appendices, Section E.9; "Carrot" Item was replaced by the "Cake" Item, Appendices, Section E.11; "Book" Item was replaced by the "Curtain" Item, Appendices, Section E.12; "Clown" Item in Appendices, Section E.21).

10.7.3 Two relations in one single element

The "Baby carriage" Item was also problematic because there were 2 relations in one element: a standing or walking woman/man. We decided to remove the standing/walking relation and to add another one (type of object). And again, we decided to remove the ground/grass distinction because it was too often present in the entire test. We replaced it by a grass/snow relation[16] (see "Baby Carriage" Item in Appendices, Section E.23).

10.7.4 Modifications of the possibilities of answers

Besides these changes, we also modified some of the possible answers in the classic version. Indeed, in some items, the possibilities of answer were sometimes too easy. For instance, in the "Tree" Item, there was only one picture that presented the fallen fruit. Once the participants had noticed that they needed fallen fruits, it was easy for them to find the right

[16] The "Baby Carriage" Item presents a boy who wears shorts, which seems a little weird in the snow. This item will be changed and the boy will wear trousers.

picture without observing the others. So, we decided to change some of the picture suggestions (see “Tree” Item in Appendices, Section E.24).

11. CONCLUSION

11.1 FUTURE PERSPECTIVES

11.1.1 The analogical reasoning test

Our AR test (CAM-R) was not a real learning test, as defined by the psychologists and researchers. We standardized our instructions and we put a training phase. However, we did not use a pretest-intervention-posttest design, and we did not select a control group receiving different tests as the experimental group.

In order to improve the design of our test, we propose to add a preliminary phase, which could train the participants how to compare elements. For example, an item could propose a red ball on the top of the screen and several objects at the bottom of the screen, such as a green square, a yellow circle and a red ball. The task could be to find the same object as the one placed on the top of the screen. Another item could propose to compare the objects in terms of color, shape or size. This preliminary phase could be ideal to familiarize the participants with the comparison of objects in terms of similarities and differences. This phase could be followed by a training phase, the same that we used in our test, and then by the analogical matrices.

As stated before, the administration of the CAM-R provoked a ceiling effect, which indicated that both versions were too easy for some of our participants. They did not really benefit from the external memories as we expected. In order to increase the difficulty of the test, we propose to add 3 more levels of complexity and hence more relations (from 2 in the first level to 8 in the seventh level), which could suit older children. As stated in the theoretical background, the difficulty of analogies is partly represented by the number of relations. Adding more complex levels can have 2 effects: it can indicate how many relations the participants could treat, because they could perhaps treat more than 5 relations; it can also make the external memories more useful: they were not very useful with 5 relations to treat at the same time in the construction version. The addition of more levels will probably improve the distinction between the construction version and the classic version, in particular for young children. This addition would also allow more discrimination between the participants, as some would be able to solve items of the seventh level of difficulty, whereas other could be limited to the fifth level of difficulty. In sum, we propose to add 3 more levels of difficulty, each composed of 4 items. The total of the test would be increased by twelve items and would finally contain thirty-six items instead of twenty-four.

11.1.2 The touch screen computer tool

At the beginning of our empirical part, the support workers and the teachers warned us that the daily tasks used with our participants usually lasted approximately 10 to 15 minutes. However, each of our versions lasted 30 minutes and all participants were able to complete each version. As mentioned before, theoretically, individuals with ID tend to demonstrate a lack of attention and are easily distracted by disturbing elements. It seems that our attractive device (touch screen computer) and the attractive pictures increased our participants' attention span, and because of this it was maintained twice or three times longer than their usual attention span. The attention of our participants was also maintained due to our feedback procedure. As stated by Nippold and Sullivan (1987), the action of speaking to the participants during the test helped to maintain their attention.

Thanks to the positive outcome, the support workers were very enthusiastic with the beneficial effects of the touch screen, in particular, the increased attention span and the fact that the students with ID could act on the computer. ID students often had motor skill deficits that hampered them from manipulating the computer mouse. Due to having the touch screen, their movements did not need to be very precise.

As a result, the support workers asked us to create several tasks that could be useful for training students with ID to function better in their daily lives. In collaboration with the institution "Fondation Ensemble", several tasks were created on the touch screen computer. The support workers described what they wanted and we computerized the tasks according to their wishes. For example, they asked for a task that differentiated between the different seasons or between cold and hot. In these tasks, the participants needed to place several objects in either one category (e.g., summer) or in another (e.g., winter). Another task proposed recycling, in which the participants needed to put several objects in one of the suggested categories (e.g., paper, glass, or aluminum). All these tasks and several others were designed to enhance the students' motivation. The new format and device provided discussion between the students and improved their attention span and their level of accomplishments.

11.2 FINAL CONCLUSION

In our theoretical part, we mentioned several studies that highlighted the difficulty of individuals with moderate ID to deal with AR tasks because they tended to have a shorter memory span and found it difficult to handle the increasing number of elements and relations (e.g., Hulme & Mackenzie, 1992; Mulholland *et al.*, 1980). These observations motivated us to design an experimental situation (construction version of the CAM-R) in which the participants could solve the AR items without being confronted with a memory overload.

Our results have educational benefits for individuals with moderate ID because the study showed that moderate ID participants were able to solve analogical matrices of different levels of complexity. ID-low also received results equal to children of the same mental age when the test version offered external memories. These external memories enabled our participants to go beyond their memory span limit. Indeed, they were able to solve items composed of 5 relations, whereas their memory span can usually treat 2 or 3 relations at a time, which was also true for the youngest children. In his article, Büchel (2006) stated that the problem was to know if persons with moderate ID had a limitation in AR or rather a memory limitation. Our results indicated that with a support, these participants were completely able to reason by analogy and did not have a limitation in this area. On the contrary, their problem was more located in their memory, which could be enhanced with external help, as we demonstrated it.

It seemed that an appropriate device, in this case a touch screen computer test with external memories, allowed better performances for individuals with moderate ID on an AR task. Ergonomics that considered the interaction between individuals and computers defined 3 dimensions that needed to be taken into consideration in order to make easier the introduction of a new technology (Dillon & Morris, 1996), such as, its utility, its usability, and its acceptability (Bétrancourt, 2007). We assume that our AR test (CAM-R) incorporated these 3 characteristics. Its utility was confirmed because it acquired an interest from all the participants compared to other traditional tests (e.g., Raven's CPM). Secondly, its usability was also confirmed because all individuals were able to use the computer test in order to solve the AR items. In addition, they did not complain about the test length and were satisfied with the test. Finally, its acceptability was also confirmed because it assimilated changes in the tasks format that compared with everyday tasks; it provoked more attention, and increased the participants' attention span. Additionally, the participants with ID could realize that they were able to use the computer like everyone else, which was very important for their self-confidence, because the touch screen computer increased this feeling of direct manipulation with objects (Norman, 1991; Norman & Draper, 1986).

Educational implications of these types of studies go against what is generally supposed by professionals: individuals with moderate ID were able to reach higher abstract reasoning levels than what is usually expected from them. Besides these positive outcomes, we also observed that the level of attention span of our participants increased. As mentioned before, theoretically, individuals with moderate ID tend to demonstrate a lack of attention and tend to be distracted by disturbing elements, which was not observed in our study.

A number of studies have shown that computers were motivating, especially for persons with moderate ID. They were perceived as interesting, fun, and nonjudgmental when providing help or feedback, which did not lower their self-esteem (e.g., Bernard-Opitz *et al.*, 2001; Foshay & Ludlow, 2005; Hetzroni & Tannous, 2004; Standen *et al.*, 2001). Using computer technologies has been found to be more motivating for these individuals than any other kind of device, such as what is often found in traditional instruction (Moreno & Saldaña, 2005). Moreover, each participant worked at his/her own rhythm, which was one of the numerous advantages of the computer (Cromby *et al.*, 1996; Standen & Brown, 2005; Standen *et al.*, 2001).

Even if the use of computers cannot completely overcome the difficulties and limited functions that are associated with a moderate ID, our research showed that this device enhanced performances and reduced the memory load, as it was demonstrated by other studies (Brown, 2011; Foshay & Ludlow, 2005; Papastergiou, 2009). Following the obtained results, we intend to develop a new version of the test composed of more levels and hence more relations, in order to observe and assess the maximum number of relations with which students with moderate ID can cope.

There is now growing recognition that computers enhance skills that are very important for the well-being of individuals with moderate ID and for young children alike. In conclusion, our AR test was useful to detect AR abilities in students with moderate ID and to enable the support workers to discover the beneficial effects of the touch screen. Generally, they have low expectations toward the capacities of persons with ID (Robinson et al., 2000). With our study, they discovered the attention maintenance of the students, and they now have a better opinion of their abilities in several tasks.

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