Université de Montréal

L'examen de la fonction exécutive à 5, 6 et 7 ans et de son rôle dans le lien entre l'inhibition comportementale et les symptômes anxieux à 7 ans.

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Résumé

L'autorégulation se définit comme la capacité à exercer un contrôle sur ses pensées, ses émotions et ses comportements dans l'atteinte d'un but. Elle permet de s'adapter aux événements de la vie difficiles ou situations nouvelles telles que la transition préscolaire-scolaire. Selon la perspective développée par Blair et Raver (2015), l'autorégulation est un système composé de cinq niveaux hiérarchiques réciproquement reliés: les gènes, la physiologie, le comportement, l'émotion et la cognition. L'objectif principal de cette thèse est d'examiner, pendant la transition préscolaire-scolaire, le développement de trois de ces cinq niveaux du système de régulation : cognitif, comportemental et émotionnel. Elle comporte deux articles empiriques.

Le premier article examine deux modèles développementaux complémentaires de la flexibilité cognitive: le traitement itératif (Zelazo, 2015,) qui identifie les mécanismes neurocognitifs selon lesquels les patrons développementaux de la flexibilité peuvent émerger et la théorie des catastrophes (van Bers et al., 2011), qui se concentre sur les caractéristiques quantitatives et qualitatives de l'amélioration de cette performance. Spécifiquement, l'étude, qui utilise une analyse à décalages croisés, explore les associations longitudinales et bidirectionnelles de l'exactitude et du temps de réaction dans une tâche mesurant la flexibilité cognitive (DCCS blocs mixtes) à 5, 6 et 7 ans. L'étude examine également le rôle de la mémoire de travail et du vocabulaire comme médiateurs potentiels entre le temps de réaction et l'exactitude. Les résultats montrent qu'un ralentissement à 5 ans et à 6 ans au DCCS précède l'amélioration de l'exactitude au DCCS, qui ensuite prédit une augmentation de l'efficacité (vitesse) à 7 ans. La mémoire de travail agit comme un médiateur partiel entre un ralentissement à 5 ans et une meilleure exactitude à 6 ans.

Afin de mieux comprendre le rôle du développement de la flexibilité cognitive et de la mémoire de travail dans l'adaptation socio-affective lors de cette transition, le deuxième article étudie l'interaction entre l'inhibition comportementale à 5 ans et ces deux fonctions exécutives à 6 ans en vue de prédire l'anxiété à 7 ans. Les résultats suggèrent que l'inhibition comportementale à 5 ans est positivement associée à des symptômes d'anxiété à 7 ans, mais seulement lorsque les enfants montrent des niveaux d'exactitude faibles de la flexibilité cognitive ou de la mémoire de travail à 6 ans. De bons niveaux d'exactitude de flexibilité cognitive ou de mémoire de travail à 6 ans, seraient un facteur protecteur. Ces résultats suggèrent que les différences individuelles dans le développement de la flexibilité cognitive et de la mémoire de travail permettent de prédire l'anxiété à l'enfance chez les enfants présentant une inhibition comportementale élevée. Les résultats des deux articles ont démontré que la transition préscolaire-scolaire s'avère une période de développement rapide et de réorganisation des compétences en flexibilité cognitive. Pendant son développement, la flexibilité cognitive et la mémoire de travail sont des facteurs protection pour les enfants ayant une inhibition comportementale élevée. Ainsi, la discussion générale de la thèse abordera la contribution aux modèles développementaux autour de la transition scolaire et l'implication des résultats des deux articles sur les recherches futures et l'intervention psychoéducative.

Mots clés : Flexibilité cognitive, mémoire de travail, inhibition comportementale, anxiété, étude longitudinale, modération, analyses croisées, transition scolaire.

Abstract

Self-regulation is defined as the ability to exercise control over thoughts, emotions and behaviors in order to achieve a goal. It supports adaptation to life events and to difficult or new situations such as the preschool-to-school transition. According to the perspective developed by Blair and Raver (2015), self-regulation is a system composed of five reciprocally linked hierarchical levels: the genes, the physiology, the behavior, the emotion and the cognition. The main objective of this thesis is to examine, during the preschool-to-school transition, the development of three of these five levels of the regulatory system: cognitive, behavioral and emotional. It includes two empirical studies.

The first study examined two complementary developmental models of cognitive flexibility: iterative processing (Zelazo, 2015,) which defines the neurocognitive mechanisms by which developmental patterns of flexibility can emerge, and catastrophe theory (van Bers et al., 2011), which clarifies the quantitative and qualitative characteristics of improving performance. Using cross-lagged analysis, this first study explored longitudinal and bidirectional associations between accuracy and reaction time in a task assessing cognitive flexibility (DCCS mixed blocks) at ages 5, 6 and 7. The study also examined the role of working memory and vocabulary as potential mediators between reaction time and accuracy. The results showed that slower reaction times at 5 and 6 years in the DCCS preceded the improvement in accuracy in the DCCS, which then predicted an increase in efficiency (speed) at seven years. Working memory acted as a partial mediator between slowing down at 5 years and improved accuracy at 6 years, as suggested by the iterative processing model.

In order to better understand the role of cognitive flexibility and working memory in child socio-affective adjustment during the preschool-to-school transition, the second study examined the interaction between behavioral inhibition at 5years and two executive function domains (cognitive flexibility and working memory) at 6 years in order to predict anxiety at 7 years. The results showed that behavioral inhibition at age 5 was positively associated with anxiety symptoms at age 7, but only when children showed low levels of accuracy in cognitive flexibility or working memory at age 6. High levels of cognitive flexibility or working memory accuracy at age 6 thus may act as protective factors. These results suggest that individual differences in the development of cognitive flexibility and working memory play an important role in the prediction of anxiety for children with high behavioral inhibition.

Taken together, the results of the two studies suggest that the preschool-to-school transition corresponds to a rapid developmental period and of reorganization of cognitive flexibility. Further, during this period of dynamic development, cognitive flexibility plays an important protective role for children with high behavioral inhibition. The general discussion addresses the thesis' contribution to developmental models during the school transition and the implications of the results of the two studies for future research and psychoeducational intervention to facilitate adjustment during the preschool-to-school transition.

Keywords: Cognitive Flexibility, Working Memory, Behavioral Inhibition, Anxiety, Longitudinal, Moderation, Cross-Lagged Panel, School Transition.

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ADHD: Attention Deficit / Hyperactivity Disorder

AIHW Australian Institute of Health and Welfare

AX-CPT: AX-Continuous Performance Task

ANOVA: Analysis of variance

AWMA: Automated Working Memory Assessment battery

BI: Behavioral Inhibition

BD: Block Design

BRIEF: Behavioral Rating Inventory of Executive Functions

DCCS: Dimensional Card Change Sort

DCCS-C: Dimensional Card Change Sort Child version

DCCS-P: DCCS: Dimensional Card Change Sort Puppet version

DSM-V: Diagnostic and Statistical Manual of Mental Disorders, Fifth Edition

ÉLDEQ : Étude longitudinale du développement des enfants du Québec, l'ÉLDEQ

ERP: Event Related Potentials

EF: Executive Function

EM-FIST : Emotional Flexible Item Selection Task

EVIP: Évaluation du Vocabulaire en Images Peabody

FIST: Flexible Item Sorting Task

FIML: Full information maximum likelihood

GLM: generalized linear model

IC: Inhibition comportementale

IR: Iterative Reprocessing

MLR: Maximum likelihood with robust standard errors

MCT: meta-cognitive therapy

NEPSY: A Developmental NEuroPSYchological Assessment

NIH: National Institutes of Health

PPVT-R: The Peabody Picture Vocabulary Test-Revised

QLSCD The Québec Longitudinal Study of Child Development

ROST: Random Object Span Task

RT: Reaction time

SD: Standard deviation

SRMR: standardized root mean squared residual
RMSEA : root mean square error of approximation

WISC-IV: Wechsler Intelligence Scale for Children Fourth Edition

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1 INTRODUCTION GÉNÉRALE

L'autorégulation se définit comme la capacité à exercer un contrôle sur ses pensées, ses émotions et ses comportements dans l'atteinte d'un but (Blair et Raver, 2012). Elle permet de s'adapter aux événements de la vie et aux situations difficiles ou situations nouvelles telles que la transition préscolaire-scolaire (Hosch et al., 2022). Elle comprend, mais sans s'y limiter, des attributs tels que la régulation des émotions et les comportements orientés vers un but. L'autorégulation s'illustre par une bascule flexible entre une réponse réfléchie ou réactive en fonction du contexte. Des études longitudinales (Lonigan et al., 2017; Moffitt et al., 2011) et des méta-analyses (Robson et al., 2020; Smithers et al., 2018) ont démontré la valeur prédictive de multiples indicateurs d'autorégulation dans le développement adaptatif, dont la transition préscolaire-primaire (Blair et Raver, 2015), la réussite scolaire (Mischel et al., 1988) et la santé mentale (Robson et al., 2020). Selon Blair et Ku (2022), l'autorégulation est un système composé de cinq niveaux hiérarchiques réciproquement reliés : au niveau inférieur se trouvent les gènes (p. ex. :gène qui code pour la sensibilité aux hormones impliquées lors d'un stress tel que l'activation de glucocorticoïde cortisol et au niveau supérieur se trouvent la physiologie (réactivité et réponse au stress), le comportement (p. ex. : tempérament, personnalité), l'émotion (régulation de l'intensité de la réponse émotionnelle) et la cognition (de la fonction p. ex. :exécutive et du contrôle attentionnel volontaire) . Par l'entremise de boucles de rétroaction, les niveaux s'influencent selon un mécanisme de bas en haut (« bottom-up ») et un mécanisme de haut en bas (« top-down »). Les mécanismes de bas en haut, qui s'inscrivent dans le niveau des gènes et dans les systèmes limbique, endocrinien et hippocampique, impliquant les réponses automatiques du stress physiologique. Ce mécanisme engage des réponses réactives, automatiques, dont un contrôle de l'attention involontaire guidé par les systèmes d'alerte et d'orientation centré sur un danger potentiel. Ainsi, le contrôle volontaire de l'attention serait diminué au profit d'un système automatique de bas en haut. Les mécanismes de haut en bas, localisés dans le cortex préfrontal, réfèrent quant à eux à un processus volontaire et réfléchi impliquant le niveau cognitif de la régulation, dont la fonction exécutive et le contrôle d'attention volontaire selon le principe de Yerkes et Dobson (Blair et Ursache, 2011), le niveau d'excitabilité du stress, de l'émotion et de l'attention influence, selon une courbe quadratique (u inversé), le niveau cognitif, dont la fonction exécutive. Ainsi, lorsque le niveau de stress, d'émotion ou d'attention de contrôle involontaire est trop élevé ou trop faible, l'activité de la fonction exécutive est inhibée au profit des mécanismes de bas en haut. Une réaction automatique sera exprimée au détriment d'une réponse réfléchie. Ce principe d'interférence a été confirmé pour les tâches impliquant les cognitions complexes, dont la fonction exécutive (Diamond et al., 2007). Toutefois, toujours selon le modèle d'autorégulation : à des niveaux modérés de stress et d'émotion, des mécanismes inverses de haut en bas, comme ceux de la fonction exécutive, atténueraient les mécanismes de bas en haut, dont la régulation du stress et de la réactivité comportementale. Ainsi, la fonction exécutive viendrait aider à réguler les tendances automatiques découlant du tempérament (p. ex. : inhibition comportementale) ou à réguler une réaction émotionnelle. Une rétroaction entre chaque niveau de régulation, en interaction avec le contexte, permettrait le développement de ce système régulateur.

Bref, selon Blair et collègues, l'enfant serait prêt à aller à l'école lorsque ses niveaux supérieurs seraient assez développés pour permettre de réguler les émotions et les comportements afin de s'engager dans les activités d'apprentissages lors de la période de transition préscolaire-scolaire. La présente thèse s'intéresse au développement de trois de ces cinq niveaux du système de régulation pendant la transition préscolaire-primaire: cognitif, comportemental et émotionnel. Le premier article examine le développement du niveau cognitif uniquement, spécifiquement le développement de la flexibilité cognitive pendant la transition préscolaire-primaire, soit à 5 ans, 6 ans et 7 ans. Effectivement, selon Blair, un développement des FE lors de la transition préscolaire-scolaire est nécessaire pour permettre un contrôle des niveaux inférieurs. Le deuxième article se penche sur les relations entre les trois niveaux, en étudiant le tempérament de type inhibé à 5 ans (comportement) et la fonction exécutive à 6 ans (cognitif) pour prédire l'anxiété à 7 ans (émotif). Spécifiquement, tel que suggéré par Blair, nous explorons si le niveau cognitif interagit ou explique la relation entre le comportement (tempérament inhibé) et l'émotion (anxiété).

1.1 La fonction exécutive : définition et conséquences

Dans le modèle de régulation de Blair et Ku (2022), la fonction exécutive est associée au niveau supérieur. Elle est désignée comme étant la composante cognitive et intentionnelle de la régulation. Elle est impliquée dans la régulation des niveaux inférieurs, dont les réactions émotionnelles et comportementales. La fonction exécutive désigne un ensemble de processus cognitifs qui soutiennent le contrôle intentionnel de la pensée, de l'action et de l'émotion vers l'atteinte d'un but. Elle est nécessaire pour la résolution de problèmes et l'adaptation à de nouvelles circonstances (Miyake et al., 2000). La fonction exécutive est positivement liée à la réussite scolaire des enfants (Ahmed et al., 2018; Cragg et Gilmore, 2014; Purpura David et al., 2017; Willoughby et al., 2019). De plus, la fonction exécutive à l'enfance est un prédicteur de la santé physique, de la dépendance aux substances et du statut socio-économique et du risque de commettre un crime à 32 ans (Aytaclar et al., 1999; Moffitt et al., 2011). Par des analyses confirmatoires latentes réalisées sur deux échantillons (131 collégiens et 108 enfants âgés entre 8 et 13 ans), il est démontré que trois dimensions distinctes de la fonction exécutive sont modérément corrélées : (1) l'inhibition cognitive (2) la flexibilité et (3) la mise à jour et le monitorage de la mémoire de travail (Lehto et al., 2003; Miyake et al., 2000). L'inhibition cognitive permet de supprimer délibérément les réponses à un stimulus (ex : ignorer une distraction), la mémoire de travail permet de garder en tête les informations et de les manipuler et la flexibilité cognitive permet le basculement entre les perspectives, les règles ou les tâches.

1.1.1 Historique du concept de la fonction exécutive

Historiquement, le construit de la fonction exécutive a été développé à la suite de aux travaux des anatomistes des 18e et 19e siècles qui cherchaient la localisation des fonctions mentales dans différentes régions du cerveau, ainsi qu'aux études d'observation des lésions du cortex préfrontal. En 1840, l'une des célèbres études de cas est sans nul doute celle du cheminot Phineas Gage, dont une tige de métal avait transpercé le lobe orbitofrontal à la suite d'un accident (Benson et Sabbagh, 2010). Comme il avait subi la perte d'une partie de son lobe frontal, un changement important s'était opéré au niveau de sa personnalité et de son jugement, mais son quotient intellectuel aurait été préservé. Ces premières études de cas ont graduellement permis de définir globalement les fonctions reliées aux cortex frontaux, en situant leur rôle sur les actions dirigées vers un but (Pennington et Ozonoff, 1996). Avant les années 1960, l'aspect développemental de la fonction exécutive était quasiment absent des théories anatomistes, celles-ci statuant que le lobe frontal n'atteignait pas sa maturité avant l'adolescence (Pennington et Ozonoff, 1996). Les travaux de Luria (1966) ont offert des assises théoriques et empiriques sur l'organisation hiérarchique du fonctionnement du cerveau, incluant la fonction exécutive comme niveau supérieur de régulation (*Top-Down*). Aujourd'hui, le rôle du cortex préfrontal et de l'implication des autres régions du cerveau dans le développement de la fonction exécutive dès la petite enfance sont beaucoup mieux connus (Zelazo, 2020).

1.1.2 Études transversales et longitudinales de la fonction exécutive pendant la transition préscolaire-primaire et enjeux méthodologiques

La majorité des études ayant examiné le développement de la fonction exécutive à l'âge préscolaire-scolaire sont de type transversal (Chevalier et al., 2014; Davidson et al., 2006, Dowset et al., 2000; Garon et al., 2013). Les études transversales ont permis de confirmer le développement des trois principales dimensions de la fonction exécutive des enfants de 2 ans (De Luca et Leventer, 2008). Les trois principales fonctions exécutives sont modérément reliées entre elle (Miyake et al., 2000). Des études supplémentaires sont nécessaires pour examiner si elles forment un facteur commun ou des facteurs séparés pendant la transition préscolaire scolaire. Afin de faire une comparaison valide entre les âges, les chercheurs soumettent à une même tâche des groupes d'enfants d'âges différents. La tâche doit répondre à trois composantes: nouveauté, complexité et intégration de l'information (Anderson et al., 2008). Ainsi, une même tâche doit montrer un niveau similaire de complexité tant à l'âge préscolaire que scolaire. Pour y arriver, on doit utiliser, dans la majorité des tâches, deux indices de performance : exactitude et temps de réaction. Alors que l'exactitude est utilisée comme indice de performance à l'âge préscolaire, le temps de réaction ou une combinaison de l'exactitude et du temps de réaction sont utilisés à l'âge scolaire.

À titre d'exemple, une des batteries récentes les plus utilisées en recherche développementale, la Boîte à Outils des Instituts Nationaux de la Santé aux États-Unis (le National Institutes of Health – NIH - Tool Box), comprend un ensemble de tâches validées pouvant mesurer les trois principales dimensions de la fonction exécutive à travers les âges de la vie (Zelazo et al., 2013). Le Dimensional Change Card Sorting (DCCS, (Zelazo, 2006)) est utilisé pour mesurer la flexibilité cognitive, le Flanker test est utilisé pour mesurer l'inhibition cognitive et le List Sorting Working Memory Test pour tester la mémoire de travail. Dans une étude de validation de la NIH Toolbox, les trois tâches ont été assignées à 177 enfants âgés entre 3 et 15 ans (Zelazo et al., 2013). Les trois tâches montrent une amélioration lors de la transition préscolaire et scolaire et deux de ces tâches atteignent un effet plafond au niveau de l'exactitude rendu à l'âge scolaire. Dans le DCCS standard, les participants trient des cartes représentant des images bidimensionnelles (par exemple, des chevaux oranges et des tasses brunes) qui peuvent être classées selon l'une ou l'autre dimension (par exemple, la couleur ou la forme). En d'autres termes, l'une ou l'autre carte peuvent être classées en fonction des règles de tri (par exemple, un cheval brun pourrait être trié avec le cheval orange ou la tasse brune) (Zelazo, 2006). Lorsque l'enfant atteint un âge où il réussit cette étape, une version plus complexe est proposée dans laquelle la règle de classement change de manière imprévisible. La plupart des enfants de 3 ans ont tendance à persévérer dans le changement de dimension lors du DCCS, en continuant à utiliser la règle de départ, alors que les enfants de 5 ans réussissent à classer selon la deuxième dimension (Zelazo, 2006). Au début de l'âge scolaire un effet plafond est observé pour la partie plus complexe. Un score combiné (exactitude et temps de réaction) est alors utilisé pour pallier l'effet plafond.

Toujours à titre d'exemple, le même principe de calcul de score est utilisé pour la tâche d'inhibition cognitive, la Eriksen Flanker Task, comme on observe également la présence d'un effet plafond. (Eriksen et Eriksen, 1974). Dans cette tâche, cinq poissons sont montrés sur un écran d'ordinateur. Il est demandé à l'enfant d'identifier dans quelle direction nage le poisson du centre sans se laisser distraire par la direction de nage des quatre autres poissons. Dans la majorité des essais, le poisson nage dans une direction (16 essais congruents) et dans les autres, le poisson nage dans l'autre direction (9 essais non-congruents). Le score final est calculé à partir du nombre d'essais non congruents réussis et du temps de réaction. L'image des poissons est remplacée par une image de flèche pour les enfants de 8 ans et plus : ils doivent alors identifier le sens de la flèche du milieu. Comme dans le DCCS, une progression est observée après trois ans et l'utilisation du score de temps de réaction est nécessaire lorsque l'enfant atteint le seuil de 80% (Zelazo et al., 2013).

Finalement, pour ce qui est du test pour mesurer la mémoire de travail, la tâche Toolbox List Sorting Working Memory (Tulsky et al., 2013) consiste en une série d'images présentée de manière visuelle et auditive sur un écran d'ordinateur, une image à la fois à un rythme de 2 secondes par stimulus. Les participants doivent ensuite nommer toutes les images vues à l'ordinateur par ordre croissant de taille réelle, du plus petit au plus grand. Dès l'âge de 3 ans, la majorité des enfants comprennent la séquence de petit à grand et leur score d'exactitude s'améliore jusqu'à l'adolescence (Tulsky et al., 2014).

En somme, à partir de tâches validées, comme celles du NIH Toolbox, les données transversales permettent de conclure que la fonction exécutive peut être évaluée très tôt dans la vie et qu'elle s'améliore à travers le temps. L'utilisation de deux indicateurs, l'exactitude et le temps de réaction, pourrait donc être importante pour pallier l'effet plafond souvent observé dans les tâches mesurant les fonctions exécutives entre l'âge préscolaire et scolaire. Toutefois, la relation entre ces deux indicateurs à travers le développement chez les mêmes enfants, particulièrement lorsqu'il y a cette bascule entre l'utilisation de l'indicateur d'exactitude pour l'utilisation du temps de réaction, n'a pas encore fait l'objet d'études. Afin de répondre à cette limite, l'objectif de la première étude sera d'examiner la relation entre ces deux indicateurs de performance lors d'une seule tâche, celle de flexibilité cognitive, le DCCS blocs mixtes à 5 ans, 6 ans et 7 ans.

En effet, pour être une mesure valide et cohérente de la stabilité et du changement à travers le développement, la même tâche doit être répétée dans le temps dans le même groupe de participants (Zelazo et al., 2013). Un devis longitudinal évaluant les mêmes enfants à travers le temps est donc nécessaire pour nous informer s'il existe une séquence de changements dans le développement cognitif, car les comparaisons entre les âges se font à partir des mêmes enfants. De plus, l'utilisation des mêmes participants à travers le développement permet de dégager les différences inter-individuelles dans les changements intra-individuels.

Cependant, une minorité d'études utilisent un devis longitudinal pour examiner le développement du contrôle d'attention volontaire de la fonction exécutive (Camerota et al., 2019; Clark et al., 2013; Hughes et al., 2013). De manière générale, les études longitudinales concluent qu'il y a une amélioration plus rapide de la fonction exécutive un peu avant et pendant la transition préscolaire et scolaire pour les trois dimensions de la fonction exécutive (Zelazo, et al, 2016). Par exemple, selon un devis prospectif à cohorte séquentielle, 388 enfants ont complété une tâche exécutive mesurant l'inhibition cognitive et la flexibilité cognitive (Espy, 1997) avant l'entrée à l'école, soit à 3,5 ans, à 3,75 ans, à 4,5 ans et à 5,25 ans. L'étude montre un gain rapide de l'inhibition cognitive entre 3,5 ans et 3,75 ans, alors que la flexibilité cognitive montre une amélioration linéaire et moins rapide que l'inhibition cognitive. Une seconde étude longitudinale incluant 191 enfants ayant complété deux tâches exécutives à 4 et 6 ans – une tâche d'inhibition cognitive et une tâche liée à la mémoire de travail – démontre également une amélioration importante pendant cette période (Hughes et Ensor, 2011).

Les études longitudinales tentent de mieux comprendre cette amélioration rapide de la fonction exécutive lors de la transition préscolaire-scolaire (Zelazo et al., 2016). L'étude longitudinale de Wiebe et al., (2012) a permis d'examiner le développement de l'inhibition cognitive et de ses mécanismes sous-jacents au développement entre 3 ans et 5,25 ans. Une bonne mémoire de travail et de bonnes habiletés cognitives générales étaient liées à de meilleures performances d'inhibition cognitive à 5,25 ans. Encore peu d'études longitudinales se sont attardées à mieux comprendre les mécanismes sous-jacents à l'amélioration de la flexibilité cognitive pendant la transition du préscolaire au primaire.

1.1.3 Rôle de la fonction exécutive sur l'adaptation scolaire et socio-affective pendant la transition préscolaire-primaire

Le rôle de la fonction exécutive dans l'adaptation scolaire et pour certaines composantes du développement socio-affectif a été démontré dans des études longitudinales, transversales et méta-analyses. Le développement socio-affectif est défini par quatre composantes : émotionnelle (incluant les problèmes extériorisés et intériorisés), social, concept de soi et auto-régulation (Sow et al., 2022). D'une part, quelques études ont démontré le caractère prédictif de la fonction exécutive à la réussite scolaire. Par exemple, l'inhibition cognitive mesurée pendant la période préscolaire a été identifiée comme prédicteur de la réussite en mathématique au primaire (Ribner et al., 2017) et au secondaire (St Clair-Thompson et Gathercole, 2006). La mémoire de travail mesurée à 54 mois a été établie comme facteur prédictif de la réussite scolaire à 15 ans (Ahmed et al., 2018). Les résultats découlant d'une méta-analyse montrent une association modérée entre les dimensions de la fonction exécutive et la réussite scolaire (Allan et al., 2014).

D'autre part, le lien entre la fonction exécutive et les troubles extériorisés a également été l'objet d'études longitudinales (Cumming et al., 2022) et de méta-analyses (Schoemaker et al., 2013; Shephard et al., 2022). De manière générale, ces études concluent à une association négative significative entre la fonction exécutive à l'âge préscolaire et les problèmes extériorisés (Pinsonneault et al., 2016). Cependant, le rôle de la fonction exécutive dans les troubles intériorisés a été moins étudié. Par contre, notons, l'étude longitudinale de Cumming et al., (2022) incluant 15 827 enfants évalués à l'automne de leur entrée à la maternelle puis une seconde fois au printemps de la même année, montre un lien négatif entre la mémoire de travail et les problèmes intériorisés rapportés par l'enseignant. Par contre, la flexibilité cognitive évaluée par le DCCS n'était significativement associée ni aux problèmes intériorisés ou extériorisés. Un patron significatif similaire pour la mémoire de travail a été observé dans une seconde étude longitudinale examinant la mémoire de travail à 3 ans et les problèmes intériorisés à 5 ans, 7 ans et 11 ans (Flouri et al., 2017). Une autre étude longitudinale incluant 8 920 enfants a testé la relation entre les trois dimensions de la fonction exécutive à la maternelle et les problèmes intériorisés en deuxième année du primaire. Seule l'inhibition cognitive était négativement liée aux troubles intériorisés de manière significative et à moindre niveau avec la flexibilité cognitive (Morgan et al., 2019). Afin d'éclaircir la relation entre les différentes dimensions de la fonction exécutive et les troubles intériorisés, les chercheurs demandent plus d'études (Cumming et al., 2022). Un des moyens proposés pour mieux comprendre les différences de résultats est de distinguer plus finement parmi les troubles intériorisés : la dépression ou l'anxiété (Cheng et al., 2021; Moffitt et al., 2007; Olino et al., 2010). Quoique l'anxiété et la dépression sont liées à un certain degré, généralement, l'anxiété précède l'apparition de la dépression à l'enfance. Effectivement, les études de prévalence sur la dépression à l'âge préscolaire et début de l'âge scolaire varie de 0 à 2%, alors que la prévalence des troubles anxieux à ces âges varie entre 10 et 20 % (Bitsko et al., 2018; Whalen, Sylvester, et Luby, 2017). Le deuxième article de cette présente thèse s'intéressera donc au lien entre le comportement, la fonction exécutive et l'anxiété à l'âge préscolaire scolaire.

1.2 L’anxiété : définition, prévalence et conséquences

L’anxiété est une émotion déclenchée par la perception ou l’appréhension d’une menace potentielle. Par sa fonction de protection, elle prépare l’humain à affronter un danger. Tous les individus ressentent de l’anxiété et apprennent à la gérer à des degrés d’efficacité différents. Tout au long du développement, les enfants manifestent des peurs et de l'anxiété de manière passagère : par exemple, la peur des étrangers survient entre 7 et 10 mois, l'anxiété de séparation entre 12 et 18 mois, etc. (Gullone, 2000). L'anxiété devient inadaptée lorsqu'elle interfère avec le fonctionnement normal et qu'elle est associée à la détresse. Les principales manifestations des symptômes d’anxiété peuvent être regroupées sous quatre dimensions: le niveau physiologique (activation du système sympathique : accélération du rythme cardiaque, transpiration, mains moites, etc.) ; le niveau cognitif (interprétation des stimuli ambigus comme menaçants, pensées internes négatives ou irréalistes, etc.) ; le niveau comportemental (fuite et évitement, isolement, etc.) et le niveau émotif (anxiété, inquiétude, etc.) (Turgeon et Gosselin, 2015). Pour qu’un diagnostic soit posé, les troubles anxieux doivent interférer de façon significative avec le fonctionnement de l’individu, ils doivent être excessifs et être présents depuis au moins 6 mois. De plus, les manifestations du trouble anxieux diffèrent selon l’âge, le type de trouble, le sexe (Weiss et Last, 2001) et la culture (APA, 2022). Selon le DSM-5-TR (2022) les troubles anxieux peuvent être déclinés en 7 catégories : anxiété de séparation, mutisme sélectif, phobie spécifique, phobie sociale, trouble panique, agoraphobie et trouble d’anxiété généralisée. L’anxiété est le problème de santé mentale le plus prévalent chez les enfants (Polanczyk et al., 2015). La prévalence des troubles anxieux est d’environ 9,8% entre 3 et 17 ans (Bitsko and al., 2022).

L'anxiété est associée à des coûts individuels, familiaux, sociaux et économiques importants, dont l'échec scolaire (Chou et al., 2011; Jokela et al., 2009; Lecrubier et al., 2000; Ringbäck Weitoft et Rosén, 2005; Woodward et Fergusson, 2001). Selon l'Organisation mondiale de la santé, les coûts associés à l'anxiété et à la dépression sont associés à une perte de mille milliards de dollars par année. L'anxiété et la dépression sont les causes principales de morbidité chez les enfants âgés 5 à 14 ans (AIHW, 2019).

Facteurs de risque individuels de l'anxiété : l'inhibition comportementale

Le principal facteur de risque individuel de l'anxiété est l'inhibition comportementale (Creswell et al., 2020), mais les processus cognitifs ont également été étudiés dans le développement et le maintien de l'anxiété (Rapee et al., 2009). Le tempérament caractérisé par une forte inhibition comportementale semble être l'un des principaux facteurs de risque précoces du développement de symptômes ou de troubles anxieux (Degnan et Fox, 2007) (Sandstrom et al., 2020). L'inhibition comportementale fait référence à un trait de tempérament modérément stable et est défini comme une inhibition réactive du comportement et du système physiologique à de nouveaux stimuli, notamment des personnes, des objets, des contextes ou des situations difficiles (Degnan et Fox, 2007). Notons que l'inhibition comportementale se distingue de l'inhibition cognitive. Alors que l'inhibition comportementale prend racine dans le système limbique et réfère à des réponses comportementales réactives, l'inhibition cognitive prend racine dans le cortex préfrontal et réfère à des réponses réfléchies et serait une des fonctions exécutives. Pendant les années préscolaires, l'inhibition comportementale peut se manifester par des expressions faciales craintives, une recherche de proximité avec les soignants, une réticence sociale, un comportement d'évitement et un style attentionnel vigilant. Le rôle de l’inhibition comportementale comme facteur de risque pour le développement ultérieur de symptômes anxieux a été démontré dans plusieurs études prospectives (Biederman et al., 2001), études longitudinales (Chronis-Tuscano et al., 2009; Hirshfeld-Becker et al., 2007) et méta-analyses (Clauss et Blackford, 2012; Sandstrom et al., 2020). Notons néanmoins qu’environ 40 % des enfants ayant une cote élevée en inhibition comportementale ne développent pas de symptômes d'anxiété plus tard (Clauss et Blackford, 2012 ;Van Bockstaele et al., 2021). Identifier les processus qui précèdent, augmentent ou diminuent cette continuité est crucial. Ainsi, des études sont nécessaires pour clarifier les facteurs développementaux qui expliquent ou modèrent l'association entre l'inhibition comportementale précoce et les symptômes d'anxiété ultérieurs, car ils pourraient aider à orienter la recherche sur la prévention des troubles anxieux.

1.3 Fonction exécutive et anxiété

D’un point de vue général, et tel que décrit plus haut, le modèle d’autorégulation de Blair fait état d’une influence réciproque qui agirait entre la fonction exécutive et l’anxiété. C’est-à-dire que la fonction exécutive, par un mécanisme de haut en bas, aiderait à réguler les émotions dont l’anxiété et inversement, l’anxiété élevée viendrait inhiber la fonction exécutive. Afin de mieux comprendre ces mécanismes, la théorie du contrôle attentionnel (Derakshan et al., 2009) porte sur les mécanismes de bas en haut en étudiant l’impact de l’anxiété sur les fonctions exécutives. Selon cette théorie, la présence d'anxiété excessive dirigerait le contrôle attentionnel sur les stimuli de menace ou sur le traitement non pertinent de la tâche, comme l'inquiétude, au détriment du traitement de moins de types de stimuli pour atteindre l'objectif (Derakshan et al., 2009). L'anxiété serait associée à un déficit au niveau de l'efficience de la fonction exécutive. L'efficience est habituellement définie par un temps de réaction plus lent, alors que l'anxiété ne viendrait pas réduire l'exactitude. Étant donné que l'anxiété mobilise déjà des processus cognitifs, un surplus de ressources cognitives devra être engagé pour résoudre une tâche, alors que l'absence d'anxiété serait liée à un moindre coût cognitif. Donc, en complément au modèle de Blair où l'anxiété viendrait inhiber la fonction exécutive, dans la théorie du contrôle attentionnel, l'anxiété aurait un impact sur un des deux indices de la performance, soit le temps de réaction.

Des méta-analyses regroupant des études transversales appuient cette hypothèse sur l'association entre l'anxiété et l'efficience : l'anxiété est associée à un temps de réaction plus long, mais elle n'est pas associée à la précision dans les trois domaines de la fonction exécutive : la mémoire de travail, l'inhibition cognitive et la flexibilité cognitive (Moran, 2016; Shi et al., 2019). Il est à noter que l'âge était un modérateur significatif dans la méta-analyse de Shi et al. (2019), mais pas dans le méta analyse de Moran (2016). L'association entre l'efficience du contrôle attentionnel et l'anxiété était plus important à l'âge adulte comparativement à l'enfance ($Q_M = 9.72$, $p < .01$). La différence entre les deux méta-analyses pourrait être attribuée à une proportion inégale entre les études incluant les adultes comparativement aux enfants. Dans les deux méta-analyses, il y a beaucoup moins d'études incluant des enfants que d'études incluant des adultes (25 études enfants / 125 études adultes pour la méta-analyse de Moran (2016) et de 10 études enfants / 58 études adultes pour la méta-analyse de Shi et coll., 2019). Depuis, la publication de ces méta-analyses, de nouvelles études ont analysé le lien entre l'anxiété et la fonction exécutive au préscolaire. Notons par exemple une étude récente ayant administré des tâches mesurant la flexibilité cognitive (DCCS), la flexibilité affective (Emotional Flexible Item Selection Task (EM-FIST) et l'inhibition cognitive (Day-Night Task) chez 67 enfants âgés de 67 mois (Mărcuș et al., 2022). Les résultats de cette étude montrent une interaction significative entre les conditions de la tâche et l'anxiété: les enfants ayant un niveau élevé d'anxiété sans toutefois nécessairement répondre aux critères diagnostiques, d'anxiété générale ont un score d'exactitude plus faible dans la tâche de flexibilité affective, mais seulement dans la condition montrant des visages exprimant la colère (et non d'autres émotions). Les autres tâches exécutives n'étaient pas associées à l'anxiété. Cependant, le score d'efficience ou de temps de réaction n'a pas été évalué. En revanche, une étude longitudinale qui ne faisait pas non plus partie des méta-analyses citées plus haut et regroupant 188 enfants a montré un lien entre la fonction exécutive à 3,5 ans et l'anxiété à 12 ans (Kertz et al., 2016). Dans cette étude, les parents ont complété à sept reprises le Behavioral Rating Inventory of Executive Functions (BRIEF), questionnaire évaluant l'inhibition et la flexibilité cognitive (Gioia et al., 2002) entre 5,42 ans et 12 ans. Le score de l'anxiété était composé au nombre de symptômes d'anxiété généralisée et/ou d'anxiété de séparation (maximum 15) évalué lors d'une entrevue semi-structurée. Selon l'étude, l'inhibition cognitive et la flexibilité cognitive à 5 ans sont associées négativement nombre de symptômes d'anxiété généralisée et/ou d'anxiété de séparation rapportée 3,5 ans plus tard. Cependant, l'utilisation du BRIEF rend les comparaisons avec les autres études limitées, car l'association est modérée entre le questionnaire et les tâches neuropsychologiques et les tâches de la fonction exécutive en laboratoire est complexe et modéré (Garon et al., 2016; Toplak et al., 2009; Toplak et al., 2013). Néanmoins, cette relation négative a été également établie dans une étude longitudinale évaluant la mémoire de travail et l'anxiété de trait (Visu-Petra et al., 2014) . Des enfants âgés entre 3 et 6 ans (N=68) ont dans un premier temps participé à l'évaluation de la mémoire de travail (utilisant l'indice d'exactitude du Automated Working Memory Assessment battery (AWMA; (Alloway, 2007) et des symptômes généraux d'anxiété utilisant le Spence Preschool Anxiety Scale (Spence et al., 2001). Neuf mois plus tard, la mémoire de travail, la flexibilité cognitive (EM-DCCS), l'inhibition cognitive (provenant de la batterie NEPSY et le Day-Night Task) et l'anxiété ont été testées chez les mêmes participants. Des analyses prospectives ont permis de noter que la mémoire de travail dans la première phase de l'étude n'était pas associée à l'anxiété dans la deuxième phase. Cependant, l'anxiété observée dans la première phase était associée négativement et de manière significative à la mémoire de travail et à la flexibilité dans la deuxième, mais pas avec l'inhibition cognitive (Visu-Petra et al., 2014). Le peu d'études longitudinales et l'utilisation d'outils différents ne permettent pas de conclure à une association robuste et fiable entre l'anxiété et la fonction exécutive pendant la transition préscolaire-primaire. L'objectif de la deuxième étude est d'examiner avec un échantillon longitudinal le lien entre les deux facteurs de risque identifiés pas la littérature : l'inhibition comportementale à 5 ans et les fonctions exécutives à 6 ans pour prédire l'anxiété à 7 ans.

1.4 Le tempérament, la fonction exécutive et l'émotion pendant la transition préscolaire-scolaire

La transition préscolaire primaire est une période où les capacités adaptatives sont engagées afin de répondre aux nouvelles exigences de l'environnement. L'enfant quitte son milieu de garde ou familial, qu'il connaît habituellement bien, pour intégrer l'école, qui demande de nouvelles exigences tant au niveau cognitif qu'affectif. La qualité d'adaptation déployée par l'enfant est reconnue comme facteur prédictif pour sa réussite scolaire future (Pagani et al., 2010) (Davoudzadeh et al., 2015). La réussite adaptative de cette période de transition s'appuie sur plusieurs facteurs englobés dans le concept d'autorégulation (Blair et Raver, 2015) : les niveaux cognitifs, émotionnels, comportementaux, physiologiques et génétiques. La relation réciproque entre les différents niveaux est un élément fondamental de l'adaptation à cette transition. L'une des relations étudiées pendant cette période est le lien entre le tempérament (niveau comportemental) et la fonction exécutive (niveau cognitif) afin de réguler la réactivité émotionnelle (niveau émotionnel) de l'enfant. Selon le type de tempérament qu'il exprime, son entrée à l'école sera différente. Un enfant avec un tempérament inhibé aura plus tendance à s'isoler de ses pairs, alors qu'à l'opposé, un enfant avec un tempérament réactif aura tendance à aller vers la nouveauté (p. ex. : son enseignante) ou vers les tâches qui lui sont présentées (Blair et Raver, 2015).

Le rôle de la fonction exécutive dans la régulation de ces prédispositions tempéramentales a fait l'objet d'une étude longitudinale regroupant 184 enfants. Cette étude a démontré que deux des dimensions de la fonction exécutive (flexibilité et inhibition cognitive) à 4 ans expliquaient le lien entre un des aspects du tempérament, soit l'affect négatif (c.-à.-d. la composante réactive émotionnelle du tempérament comme l'activation motrice, la tristesse, la frustration-colère, la timidité et la peur) à 2 ans et la réussite scolaire à 6 ans (Liu et al., 2018). Notons, néanmoins, que le modèle de Henderson, et al. (2015) (Fox et al., 2021) émet comme hypothèse, dans la relation entre l'inhibition comportementale et l'anxiété, un rôle modérateur ou médiateur des processus du contrôle cognitif centrés sur le but. Un enfant inhibé pourrait ainsi utiliser ses processus du contrôle cognitif centrés sur le but, dont la flexibilité cognitive et la mémoire de travail, afin de réguler ses réactions automatiques prenant origine dans son tempérament inhibé et ainsi atténuer ses chances de développer de l'anxiété. Tiré de ce modèle, l'objectif du deuxième article est d'examiner le rôle de la fonction exécutive et spécifiquement des stratégies de contrôle cognitif centrées sur le but, dans le lien entre le tempérament inhibé à 5 ans et l'anxiété à 7 ans pendant cette transition préscolaire scolaire.

1.5 Objectifs généraux de la thèse

Le développement de l'autorégulation est une composante importante de l'adaptation à la transition préscolaire-primaire. Il s'agit d'un système comprenant cinq niveaux : génétique, physique, comportement, émotif et cognitif. L'objectif principal de la thèse est d'examiner, pendant la transition préscolaire-scolaire, le développement de trois de ces cinq niveaux du système d'autorégulation : cognitif, comportemental et émotionnel. Elle comporte deux articles empiriques.

1.5.1 Objectifs spécifiques du premier article

Le premier article s'intéresse au niveau cognitif de l'autorégulation lors de la transition préscolaire-primaire. L'objectif du premier article est d'examiner la relation entre deux indicateurs de performance, soit l'exactitude et le temps de réaction pour une tâche mesurant la flexibilité cognitive (DCCS blocs mixtes) à 5 ans, 6 ans et 7 ans. Le rôle de la mémoire de travail et du langage comme médiateurs potentiels entre le temps de réaction et l'exactitude y est exploré, de même que le rôle de l'inhibition cognitive dans la relation entre les deux indicateurs de performance. Pour atteindre l'objectif fixé, une analyse à décalages croisés est utilisée. L'hypothèse du rôle médiateur de la mémoire de travail et du langage dans la relation entre les deux indices de performance de la flexibilité a été examinée par un test des produits des coefficients.

1.5.2 Objectifs spécifiques du deuxième article

Le deuxième article s'intéresse aux relations entre le niveau cognitif de l'autorégulation et sur les niveaux inférieurs, soit l'émotion et le comportement. L'objectif du deuxième article est d'examiner le rôle modérateur ou médiateur de la fonction exécutive à 6 ans dans le lien entre l'inhibition comportementale à 5 ans et l'anxiété à 7 ans. Pour tester l'hypothèse de modération, une analyse des modèles de régressions multiples des effets hiérarchiques principaux est effectuée entre l'inhibition comportementale à 5 ans et deux dimensions de la fonction exécutive (mémoire de travail et flexibilité cognitive) liées aux processus du contrôle cognitif centrés sur le but à 6 ans qui permettent de prédire l'anxiété à 7 ans.

Les deux articles sont réalisés dans le contexte du grand Projet longitudinal québécois sur le développement cognitif et comportemental, avec la première cohorte de l'Étude longitudinale du développement des enfants du Québec (ÉLDEQ) (n=425).

2 Méthodologie et résultats

Articles de recherche

2.1 Premier article

Transactional Longitudinal Relations between Accuracy and Reaction Time on a Measure of Cognitive Flexibility at 5, 6, and 7 Years of Age

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Objectifs spécifiques de cet article: L'objectif du premier article est d'examiner la relation entre deux indicateurs de performance, soit l'exactitude et le temps de réaction pour une tâche mesurant la flexibilité cognitive (DCCS blocs mixtes) à 5 ans, 6 ans et 7 ans. Le rôle de la mémoire de travail et du langage comme médiateurs potentiels entre le temps de réaction et l'exactitude y est exploré, de même que le rôle de l'inhibition cognitive dans la relation entre les deux indicateurs de performance.

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Contribution des auteurs

Émilie Dumont : Conceptualisation de l'article, analyse statistique, interprétation des résultats, rédaction des différentes sections de l'article, préparation des tableaux et graphiques.

Natalie Castellanos-Ryan: Soutien à la conceptualisation de l'article, à l'analyse statistique et à l'interprétation des résultats et révision de l'article.

Sophie Parent: Soutien à la conceptualisation de l'article, soutien à l'interprétation des résultats, révision de l'article.

Sophie Jacques : Soutien à la conceptualisation de l'article, à l'analyse statistique et à l'interprétation des résultats et révision de l'article.

Jean Séguin: Soutien à la conceptualisation de l'article et à l'interprétation des résultats, aide à la rédaction, correction du manuscrit et révision de l'article.

Philip David Zelazo : Soutien à la conceptualisation de l'article, à l'interprétation des résultats et révision de l'article.

Research Highlights

- Longitudinal associations between accuracy and reaction time on the DCCS at 5, 6, and 7 years were studied to examine developmental change in flexibility.
- Slowing down at 5 and again at 6 years preceded improved accuracy, which then predicted increased efficiency (speed) at 7 years.
- Working memory acted as a partial mediator between slower responding at 5 years and improved accuracy by 6 years, as suggested by the Iterative Reprocessing model.

Abstract

Whereas accuracy is used as an indicator of cognitive flexibility in preschool-age children, reaction time (RT), or a combination of accuracy and RT, provide better indices of performance as children transition to school. Theoretical models and cross-sectional studies suggest that a speed-accuracy tradeoff may be operating across this transition, but the lack of longitudinal studies makes this transition difficult to understand. The current study explored the longitudinal and bidirectional associations between accuracy and RT on the DCCS (mixed block) at 5, 6, and 7 years of age using cross-lagged panel analyses. The study also examined the roles of working memory and language, as potential longitudinal mediators between RT at Time *X* and accuracy at Time *X* + 1, and explored the role of inhibitory control. The sample consisted of 425 children from the Quebec Longitudinal Study of Child Development. Results show lagged associations from slower RT to greater improvements in accuracy between 5 and 6 years and between 6 and 7 years. Further, higher accuracy at 6 years predicted faster RT at 7 years. Only working memory acted as a partial mediator between RT at 5 years and accuracy at 6 years. These results provide needed longitudinal evidence to support theoretical claims that slower RT precedes improved accuracy in the development of cognitive flexibility, that working memory may be involved in the early stage of this process, and that accuracy and reaction time become more efficient in later stages of this process.

Keywords: Cognitive Flexibility, DCCS, Cross-Lagged Panel, Working Memory, Longitudinal, School Transition.

Transactional Longitudinal Relations Between Accuracy and Reaction Time on a Measure of Cognitive Flexibility at 5, 6, and 7 Years of Age

Executive function (EF) skills are a set of cognitive skills that support the intentional, top-down control of thought, action, and emotion, and as such, they are required for goal-directed problem solving and adaptation to new circumstances (Miyake et al., 2000). Children's EF skills are positively related to their academic achievement both concurrently and prospectively, and children who struggle with EF skills are at risk of difficulties in school (Purpura, Schmitt, et Ganley, 2017; Willoughby, Wylie, et Little, 2019). EF skills are typically measured behaviorally as three skills: inhibitory control, working memory, and cognitive flexibility (Miyake et al., 2000). Inhibitory control involves deliberately suppressing an automatic response in favor of a less reflexive response, working memory involves maintaining and manipulating information in mind, and cognitive flexibility involves switching between perspectives or task sets. EF skills overlap in early childhood and become more distinct over time (Karr et al., 2018).

To assess cognitive flexibility in both adults and children, researchers typically use some type of task-switching paradigm. These paradigms can involve three types of trials: pre-switch trials or *baseline* trials, in which a single set of rules is required (e.g., sort by color); post-switch or *switch* trials, in which a different, incompatible set of rules is introduced; and *mixed* trials, in which participants must switch between the two rule sets (i.e., task sets) from trial to trial. Furthermore, within the mixed block, one set of rules might be required more often (i.e., dominant trials vs. non-dominant trials). Using accuracy or reaction time, depending on age, participants tend to perform best on pre-switch trials and worst on mixed block trials, with intermediate performance on post-switch trials. For children around 5 to 7 years of age, accuracy and/or reaction time on the mixed block provide the most sensitive measures of cognitive flexibility.

One of the most widely used measures of task switching in young children is the Dimensional Change Card Sort (DCCS, Zelazo, 2006). In the DCCS, children are shown two target stimuli (e.g., a blue rabbit and a red boat) and told to sort a series of mismatching bidimensional stimuli (e.g., red rabbits and blue boats) by matching them to one of the target cards. During the pre-switch block, they are told to sort by one dimension (e.g., color). Then, during the post-switch block, children are told to sort the same stimuli by the other dimension (e.g., shape), requiring a reversal of responses. Finally, during the mixed block, the instructed dimension varies unpredictably, from trial to trial as indicated by the presence or absence of a black dot. To switch between dimensions, children need to detect a change in the context (black dot or the absence of it) and select the dimension (rule) associated with that context.

Most 3-year-olds tend to *perseverate* on the post-switch trials of the DCCS, continuing to use the pre-switch rules, whereas 5-year-olds typically shift successfully. While accuracy on the mixed block continues to improve beyond age 5 years, it soon approaches ceiling, and subsequent age-related improvements in cognitive flexibility are more easily observed by measuring the reaction times (RT) associated with switching between rules (Zelazo, 2006). In short, switching difficulties (i.e., *switch costs*) can be measured either in terms of accuracy or in terms of RT, as is the case for measures of task switching more generally (e.g., Dots task in Davidson, Amso, Anderson, et Diamond, 2006).

Of particular interest, sometime around 6 years of age, children appear to make a speed-accuracy tradeoff, slowing down on difficult trials in order to maintain accuracy (Davidson et al. 2006; Zelazo et al., 2013). That is, before 6 years, children respond quickly on difficult trials but with a cost to accuracy (i.e., they are more likely to err). Around 6 years, children’s accuracy typically improves but with a notable cost to RT, such that they slow down on difficult trials

(Camerota, Willoughby, Magnus, et Blair, 2020; Tikhomirov, 1978). Subsequently, accuracy typically reaches ceiling and RT costs decrease (Davidson et al., 2006).

This type of developmental pattern, from low accuracy/fast RT to medium accuracy/slow RT to high accuracy/fast RT, is expected based on at least two complementary theoretical models, the conflict cusp model (van Bers, Visser, van Schijndel, Mandell, et Raijmakers, 2011) and the Iterative Reprocessing (IR) model (Zelazo, 2015). On the one hand, catastrophe theory, generally, and the conflict cusp model (van Bers et al., 2011), specifically, focuses on quantitative and qualitative characterizations of transitions in performance to explain the developmental pattern on the DCCS from low accuracy/fast RT to medium accuracy/slow RT to high accuracy/fast RT. Relying on catastrophe theory, van Bers et al. (2011) characterize development as occurring in a dynamic system open to different influences that are complex, hierarchical, and self-organized, and that produce different types of "catastrophic" change (or catastrophes) in the system (Thom, 1975; White, 1965). The cusp catastrophe, for example, involves a transition from one stable state to another. According to the conflict cusp model of the DCCS (van Bers et al., 2011), the sequence of change around age 6 years is discontinuous, and involves three consecutive phases: *perseveration* (i.e., stable state when children fail to switch), *transition* (i.e., when children slow down and use a mix of perseveration and switching strategies), and *switching* (i.e., stable state when children switch correctly between dimensions). According to this model, the first phase is marked by a high activation of the pre-switch rule, the last phase by the high activation of the post-switch rule, and the transition phase is an activation of both rules (pre-switch and post-switch). Catastrophe "flags" are used as criteria to determine or to predict the presence of a transition phase. These include, for example, sudden jumps (spurts in development), hysteresis (regressions in development), and critical slowing down (Van der Maas, & Molenaar, 1992).

Cross-sectional studies of children's performance across the ages of 3 and 6 years on the DCCS (van Bers et al., 2011; Dauvier, Chevalier, & Blaye, 2012; Mathy, Friedman, Courenq, Laurent, & Millot, 2015) have examined the conflict cusp model, using either latent Markov models (van Bers et al. 2011) or a generalized linear model (GLM) with latent classes (Dauvier et al. 2012) to identify participants in different subgroups corresponding to the three developmental phases of DCCS performance described above. Subgroups were consistently perseverative, transitional (using two different strategies, perseveration and set-shifting), and set-shifting, in terms of accuracy. Children in the set-shifting subgroups tended to be older than the children in the perseverative groups. However, the findings for RT were less clear. For example, Dauvier et al. (2012) found evidence of a speed-accuracy trade-off, but only for the set-shifting subgroup, not the transition sub-group, and van Bers et al. (2011) did not find significant RT differences among any of the subgroups although differences were in the correct direction. In sum, the conflict cusp model can account for the sequence of cross-sectional age group differences in accuracy on the DCCS (perseveration, transition, set-switching), but how these changes relate to changes in RT remains unclear. As such, the conflict cusp model does not really address the underlying neurocognitive mechanisms involved in these developmental transitions.

On the other hand, the IR model (Zelazo, 2015) does identify underlying neurocognitive mechanisms by which this developmental pattern might emerge. According to the IR model (Zelazo, 2015), the development of cognitive flexibility, and EF skills more generally, results from increases in the efficiency with which children iteratively reprocess information, or reflect upon, the problems they face. This reflection is triggered by the detection of conflict, uncertainty, or change, and it entails slowing down, which then allows for the (re-)formulation of complex explicit rules (using language) and the maintenance of this information in mind (i.e., working memory) while solving the problem. Cognitive flexibility is made possible by reflection and the formulation and use of a high-order rule for switching between rules. Although inhibitory control can facilitate reflection by blocking the influence of bottom-up tendencies, it is not strictly necessary for reflection (Zelazo, 2015); the inhibition of inappropriate responses can occur as a by-product of flexible rule use (requiring working memory and cognitive flexibility).

According to the IR model, the development of these skills in early childhood follows a particular sequence, which produces the developmental pattern seen in performance on the DCCS. Initially, young children fail to detect uncertainty or change and respond relatively quickly making them likely to err (low accuracy/fast RT). Around 5 years of age, most children can detect uncertainty, leading them to reflect on the situation, but they do so inefficiently at first. Consequently, while accuracy improves, responding is slower (medium accuracy/slow RT). With age, the efficiency (speed) of reflection increases even as accuracy plateaus near ceiling (high accuracy/fast RT). On this account, developmental increases in performance on the DCCS (cognitive flexibility) are made possible by increases in the likelihood and efficiency of reflection, together with the development of language and working memory.

Longitudinal studies using cross-lagged panel analyses could clarify whether the 3-phase sequence of low accuracy/fast RT to medium accuracy/slow RT to high accuracy/fast RT occurs *within* individual children. For example, does better accuracy at 6 years depend on more slowing earlier at 5 years (e.g., because children who detect conflict begin to slow down and reflect before responding)? Does the relation between accuracy and RT change from being positive to negative (i.e., from better accuracy and slower RT to better accuracy and faster RT), and if so, around what age does this tipping point typically occur?

In short, to understand changes in cognitive flexibility in this age range, it is important to examine both accuracy and RT scores and to do so at several different ages in the same children.

The absence of longitudinal studies examining sequences of change in the relation between accuracy and RT makes it impossible to determine how these changes work together across time.

The current study explored the longitudinal and bidirectional associations between accuracy and RT scores on the DCCS mixed block, from preschool (5 years) to school age (6 and 7 years) using cross-lagged panel analyses (Figure 1). In order to clarify the roles of language and working memory, in the development of cognitive flexibility, the study examined vocabulary, measured by the Peabody Picture Vocabulary Test-Revised (PPVT-R: Dunn & Dunn 1981), and working memory, measured using the Random Object Span Task (ROST; Hongwanishkul, Happaney, Lee, & Zelazo, 2005), as potential mediators between DCCS RT and accuracy at Time *X* and DCCS RT and accuracy at Time *X* + 1, as proposed by the IR model (Zelazo, 2015). To clarify the role of inhibitory control in the development of flexibility, inhibitory control, measured by the Day-Night Stroop task (Gerstadt, Hong, & Diamond, 1994) at 5 years, was examined as a potential mediator or moderator of the association between RT at 5 years and accuracy at 6 years.

Three complementary predictions were tested. First, in a transactional model, slowing down should be observed before reaching high accuracy/fast RT. That is, based on the conflict cusp and IR models, it was hypothesized that slower RTs at Time *X* would predict higher accuracy prospectively at Time *X* + 1. However, after children achieve a certain level of accuracy, individual differences in accuracy should then predict faster RT in the subsequent year. Specifically, higher accuracy at age 6 years should predict faster RT at age 7 years. Second, language and working memory were expected to mediate cross-lagged relations between RT and accuracy. Third, the indirect link between slowing down at 5 years and better accuracy at 6 years through inhibitory control—measured only at 5 years, should not be significant. Nevertheless, according to the IR model, inhibitory control could potentially moderate the link between RT and accuracy by blocking the influence of bottom-up tendencies and thus facilitating reflection.

Method

Participants

Participants were part of the first cohort of the QLSCD study (Jetté, Desrosiers, & Tremblay, 1997), one of the three cohorts taking part in the larger Quebec Longitudinal Project of Cognitive and Behavior Development, together with the second cohort of the QLSCD and the Quebec Newborn Twin Study (Geoffroy et al., 2010; Renouf et al., 2010; Séguin, Parent, Tremblay, & Zelazo, 2009). One thousand French-speaking or English-speaking families from urban areas (the Greater Montreal and Quebec City areas) and varied socioeconomic backgrounds were randomly selected from the Québec birth registry in 1996 and approached to participate. Of these, a total of 572 children (51.2% girls) were followed yearly from 5 months onwards (Jetté et al., 1997). Due to attrition and variations in participation rates at individual time points, the number of participants available for analyses at one time point at least was 425. However, the number available at each time point was necessarily lower, and decreased between time points (n = 386 at 5 years; n = 316 at 6 years; n = 276 at 7 years). At 6 years of age, 62% children were monolingual speakers of either French or English, 31% children spoke more than 1 language, and 6% children spoke more than 2 languages (MacLeod, Castellanos-Ryan, Parent, Jacques, & Séguin, 2019). All measures were administered in either French (> 90%) or English (< 10%) based on parent reports of which of these two languages was their child's preferred and/or most proficient. Language of administration on any given year was unrelated to test performance. Written informed consent was provided by parents and renewed at each follow-up. Children were assessed in their homes by trained research assistants. Age 5 testing took place in the summer before children's entrance to kindergarten.

Measures

The Peabody Picture Vocabulary Test-Revised (PPVT-R)

The PPVT-R (Dunn & Dunn, 1981) or its French adaptation, the *Évaluation du Vocabulaire en Images Peabody* (Dunn, Thériault-Whalen, & Dunn, 1993) were used to assess receptive vocabulary at 5, 6, and 7 years in English- and French-speaking participants, respectively. The examiner presented a series of trials each depicting four pictures. For each trial, children identified the picture that represented the word said by the examiner. Both tests contained five training items, followed by a subset of the total items that were presented to children based on their age and abilities following a standard procedure to establish floor and ceiling items. The normative population for the EVIP was drawn from French speakers living in Canada. Scores were standardized within each language version of the test and combined into a single receptive vocabulary index.

The Random Object Span Task (ROST)

The ROST (Hongwanishkul, Happaney, Lee, & Zelazo, 2005) is an adapted version for children of the Self-Ordered Pointing Task (Petrides & Milner, 1982), which assesses visual working memory. In this version, images were presented to the children on a laptop computer fitted with a touch screen (See Supplemental Figure S1 for an example of a trial in the Supplemental Materials). Children were given the following instruction at the beginning of the task, "You will see pictures on the screen. You have to choose all of them, but only one at a time. When you have selected one with your finger, the pictures will get mixed on the screen. Then you select a different one. Do you understand? Let's start." To perform correctly on each trial, children needed to keep in mind and update the images already selected so as not to choose the same images again. There were two trials per level. The number of images to be remembered increased by 1 image for each increasing level with a maximum of 9 images. The score consisted of the total number of correct trials.

The Day-Night Stroop Task

The Day-Night Stroop task (Gerstadt, Hong, & Diamond, 1994; Montgomery & Koeltzow, 2010) was available only at 5 years[1]. The task included two parts. In the first part, the experimenter showed a picture of the sun or the moon on a computer screen. In the first part, for 10 trials, participants were first instructed to say "day" when shown the sun and "night" when shown the moon (congruent trials) In the second part, for 10 trials, participants were instructed to reverse that response set by saying "night" to a picture of a sun and "day" to a picture of a moon (incongruent trials). No feedback was provided on any trial. Accuracy consisted of the number of correct responses of the 10 trials in the second part of the task.

The Dimensional Change Card Sorting task (DCCS)

The mixed blocks version of the DCCS was administered at 5, 6, and 7 years on a laptop computer fitted with a touch screen. In the current version of the task (adapted from Zelazo, 2006), participants sorted test cards depicting bidimensional pictures (i.e., orange horses and brown cups) that could be sorted by either one or the other dimension (i.e., color or shape) onto two targets that depicted an orange cup or a brown horse. In other words, either target card could be pressed depending on the sorting rules (e.g., a brown horse could be sorted with the orange horse or the brown cup). The two sorting rules changed arbitrarily on a quasi-random basis across 20 trials, as indicated by the presence or absence of a black dot. The children were given the following instructions at the beginning of the task and again after 10 trials: "In the next game, when there is a black dot like this one, we are playing the ____ (e.g., color) game. So all the ____

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[1] Children approached ceiling performance on Day-Night Stroop at 5 years, so we do not have repeated measures for the Day-Night Stroop for all 3 time points as we do for the DCCS, PPVT, and the ROST.

(e.g., orange) pictures go here and all the ____ (e.g., brown) pictures go there. If it is ____ (e.g., orange) it goes there and if it is ____ (e.g., brown) it goes there. However, when there is no black dot we are playing the ____ (alternate; e.g., shape) game. So all…." These instructions were followed by two demonstrations and four practice trials with feedback. The DCCS score was based on 20 trials, which included 15 trials according to one dimension (i.e., the dominant dimension) and 5 trials according to the other (i.e., the non-dominant dimension). Before each trial, short verbal instructions were given to remind children of the sorting rules ("Remember, when there is a black dot you are playing the color game and when there is no black dot you are playing the shape game."). No feedback was provided on the test trials.

Accuracy consisted of the number of correct responses in the mixed block, and RT was defined as the median response time across the 20 trials of the mixed block. RTs greater than 10.00 s were coded as 10.00 s. Two median RT scores were computed, one for correct trials only, and one for all trials (both correct and incorrect). Outliers more than 3 *SD* from the mean and below 0.10 s were discarded. Also, participants' DCCS scores were excluded in a given year if participants were not cooperative, there was a problem in the administration, or the environment was disruptive, or for whom child state ratings during administration were missing. A total of 36 DCCS scores at 5 years, 15 scores at 6 years, and 5 scores at 7 years were excluded for those reasons.

Although RT scores are often based on each participants' median RT for correct trials only, we used RTs from both incorrect and correct trials for several reasons. First, the mean number of correct trials at 5 years ($M = 12.41$, $SD = 3.75$, range 2-20 20 trials, see Table 1) is typically smaller than at later ages, which reduces the reliability of the RT score. Second, the number of trials used for RT calculations varied as a function of participants' accuracy, which created a covariance between the number of trials and accuracy.[2]

Analysis Plan

The first objective of this study was to examine the transactional link between RT and accuracy scores on the DCCS mixed Block at 5, 6, and 7 years of age, as predicted by the IR model (Zelazo, 2015) and the conflict cusp model (van Bers et al., 2011). In other words, does the total accuracy score at Time *X* predict RT at Time *X* + 1 and vice versa (see Figure 1)? The second objective was to test for possible mediator roles of language and working memory at age 5 and 6 in the development of subsequent cognitive flexibility (at age 6 and 7, respectively), as predicted by the IR model—that is, whether there is an indirect effect between RT at Time *X* and accuracy at Time *X* + 1 via PPVT-R scores (i.e., receptive language as indexed by vocabulary) at Time *X* and between RT at Time *X* and accuracy at Time *X* + 1 via the ROST score (i.e., working memory) at Time *X*. Indirect effects included the cross-sectional association between RT and potential concurrent mediators (PPVT-R and ROST; i.e. both measured at the same time point (Time *X*)) rather than longitudinal (cross-lag) associations between RT and mediators. Cross-sectional associations were favored as it was hypothesized that reflection co-occurs with the development of language and working memory. The third objective was to test whether inhibitory control at age 5 (the time point at which it was available) played a mediating or moderating role in the association between reaction time at age 5 years and accuracy at age 6 years.

[2] See Supplemental Materials Figures S2a and S2b for analyses conducted with median RTs for correct trials only. When comparing the results of each analysis (one with RT scores based on all trials and the other with RT scores based on correct trials only), lower *p* values were found for similar betas in the model based on both correct and incorrect trials presented in the Results section, suggesting that the estimate of measurement error was reduced with this method.

To study this developmental process across 5, 6 and, 7 years old, cross-lagged models were performed with structural equation modeling using Mplus Version 7 (Muthén & Muthén, 2012, Asendorpf, 2021).[3] Maximum likelihood with robust standard errors estimator was used to examine cross-lagged and autoregressive effects. Cross-lagged analyses allow testing for transactional associations between variables across time (e.g., RT at 5 years associated with accuracy at 6 years), while controlling for their stability. We used a combination of indices to evaluate the adequacy of the fit of the model: Chi-square, Tucker-Lewis, the "comparative fit index" (CFI) at 0.90 or more, and the root mean square error of approximation (RMSEA) at 0.08 or less (Little, 2013). Indirect effects were tested using the bias-corrected bootstrap approach, which is recommended for small samples, as it demonstrates increased power and reliability in smaller samples (Mackinnon, Lockwood, & Williams, 2004; Fritz & MacKinnon, 2007). In order to test the main effect of DCCS RT, and those in interaction with inhibitory control at 5 years on DCCS accuracy at age 6 years, a series of linear regressions were conducted using Mplus Version 7 (Muthén & Muthén, 2012). We tested models of the moderating role of inhibitory control at age 5 years in the pathways from DCCS RT and accuracy, including both working memory and language at 5 years. Predictors and moderators were standardized, and full information maximum likelihood (FIML) was used for handling missing data. Predictors and moderators were standardized, and full information maximum likelihood (FIML) was used for handling

[3] Cross-lagged panel model (CLPM) was chosen rather than the Random Intercept Cross-Lagged panel model (RI-CLPM), because CLPM are preferred when the main goal is to assess the potential effects of change-related causes that make persons different from other persons—and not from the (long-term) average level—(Asendorpf, 2021). RI-CLPM is better suited for studies of states that typically use shorter time lags (e.g., days) between assessments and are not concerned about systematic long-term changes like here (e.g. yearly assessments).

missing data. Repeated measures ANOVAs with Greenhouse-Geisser correction were used to describe age effects for accuracy, RT, PPVT-R, and ROST scores, using SPSS Version 26.

Results

Descriptive Statistics

Table 1 describes age-related scores on three measures at each age: DCCS (accuracy and RT), PPVT-R and ROST, and the Day-Night Stroop at age 5 years. There were linear age changes for DCCS accuracy ($F(1.91,35.75) = 121.69$, $p < .001$, $\eta_p^2 = .40$), PPVT-R ($F(1.84, 381.91) = 907.67$, $p < .001$, $\eta_p^2 = .81$), and ROST scores ($F(1.97, 438.02) = 117.20$, $p < .001$, $\eta_p^2 = .35$), suggesting that these increased linearly with age. In contrast, for DCCS RT, the age effect was quadratic ($F(1.85,355.85) = 3.35$, $p = .04$, $\eta_p^2 = .03$), suggesting that age-related changes were not linear. Notably, although the mean increase in DCCS RT was not significant between 5 and 6 years of age ($p = .45$), DCCS RT was significantly faster at 7 compared to 6 years of age ($p = .01$).

Table 1

Descriptive data at 5, 6 and 7 years old for all model variables

Measures	N	Min.	Max.	M.	SD.	Skewness	Kurtosis
1. ACC DCCS 5 y	348	2	20	12.41	3.75	-0.04	-0.32
2. ACC DCCS 6 y	301	3	20	15.50	4.10	-0.69	-0.45
3. ACC DCCS 7 y	269	5	20	17.49	3.41	-1.41	0.96
4. RT DCCS 5 y	348	0.88	11.59	3.57	1.42	1.17	3.12
5. RT DCCS 6 y	301	1.56	8.10	3.81	1.16	0.94	1.25
6. RT DCCS 7 y	269	1.21	8.24	3.49	1.00	0.88	2.08
7. PPVT-R 5 y	380	10	108	61.65	18.21	-0.06	-0.36
8. PPVT-R 6 y	308	22	130	85.82	16.09	-0.58	0.67
9. PPVT-R 7 y	272	58	141	101.19	14.36	-0.15	0.10
10. ROST 5 y	386	0	12	6.00	2.39	0.01	-0.20
11. ROST 6 y	316	1	13	7.35	2.28	-0.07	-0.48
12. ROST 7 y	276	1	16	9.19	2.49	-0.24	0.07
13. Day-Night 5 y	384	0	10	8.59	2.64	-2.22	3.99

Note. Due to attrition, loss at follow up, and variations in participation rates425 participants were available at for analyses at one time point at least. However, the number available at each time point was necessarily lower, and, Ns decreased from one time to the next.
ACC = Accuracy; RT = Reaction time; DCCS = Dimensional Change Card Sort; PPVT-R = Peabody Picture Vocabulary Test-Revised; ROST = Random Object Span Task; Day-Night = Day-night Stroop task.

As shown in Table 2, accuracy and RT on the DCCS were not correlated concurrently at 5, 6, or 7 years. However, significant prospective associations between DCCS RT and accuracy were found: RT at 5 years was positively and prospectively correlated with accuracy at 6 years and RT at 6 years was correlated with accuracy at 7 years. DCCS accuracy was significantly associated with PPVT-R concurrently and prospectively across all ages. In contrast, DCCS RT did not correlate with PPVT-R concurrently at any time point, but PPVT-R at 5 years was positively and prospectively associated with DCCS RT at 6 years and DCCS RT at 6 years was positively associated with PPVT-R at 7 years. There were no significant concurrent correlations between DCCS RT and PPVT-R at ages 5 and 6 years. DCCS accuracy was concurrently and positively associated with the ROST at 6 and 7 years, and ROST at 5 years was prospectively associated with DCCS accuracy at 6 years and vice versa (i.e. bidirectional effects from 5 years to 6 years). DCCS RT scores at 5 and 7 years, but not 6 years, were concurrently and positively correlated with the ROST. Prospective associations between DCCS RT and ROST were also found: the ROST at age 7 was positively related to RT at all ages. Thus, slower RTs at all years were predictive of better working memory at age 7 years. Finally, and of note, although the Day-Night Stroop at 5 years was significantly and prospectively correlated with DCCS accuracy at 6 and 7 years, with all PPVT scores, and concurrently with ROST at age 5 years, it was not significantly associated with any DCCS RT scores nor with DCCS accuracy at 5 years.

Table 2

Bivariate correlation matrix for all model variables

Measures	1	2	3	4	5	6	7	8	9	10	11	12
1. ACC DCCS 5 y	-											
2. ACC DCCS 6 y	.14*	-										
3. ACC DCCS 7 y	.20**	.17	-									
4. RT DCCS 5 y	.04	.15*	.06	-								
5. RT DCCS 6 y	.02	.05	.17**	.15**	-							
6. RT DCCS 7 y	-.10	-.13	-.08	.03	.21**	-						
7. PPVT-R 5 y	.12*	.18**	.21**	.05	.14*	.01	-					
8. PPVT-R 6 y	.20**	.28**	.26**	.07	.09	-.01	.67**	-				
9. PPVT-R 7 y	.14*	.21**	.27**	.05	.18**	-.00	.61**	.71**	-			
10. ROST 5 y	.06	.16**	.05	.21**	.03	.06	.22**	.14*	.09	-		
11. ROST 6 y	.08	.22**	.11	.09	.10	.02	.14*	.13*	.24	.25**	-	
12. ROST 7 y	.01	.17*	.20*	.19**	.18**	.14 *	.23**	.20**	.25**	.21**	.19**	
13. Day-Night 5y	.09	.21**	.19**	.05	.08	-.03	.29**	.30**	.30**	.23**	.09	.09

**p* < .05; ***p* < .01. ACC = Accuracy; RT = Reaction time; DCCS = Dimensional Change Card Sort; PPVT-R = Peabody Picture Vocabulary Test-Revised; ROST = Random Object Span Task; Day-Night = Day-Night Stroop Task.

Cross-lagged Models

A first cross-lagged model examining accuracy and RT at 5, 6, and 7 years (Figure 2) provided an acceptable model fit: $\chi^2 = 2.18$ ($df = 3$), RMSEA = 0.00, CFI = 1.00, SRMR = 0.018. Autocorrelations show that accuracy and RT were relatively stable across time (all $\beta \geq 0.15$). More interestingly, three significant cross-lagged regression paths were found: slower RT at 5 year was significantly associated with improvement in accuracy at 6 years (i.e., change in accuracy from age 5 to 6 years; $\beta = 0.16$, $p = .01$). The same path was found between 6 and 7 years ($\beta = 0.19$, $p = .001$). In contrast, better accuracy at 6 years was negatively associated with changes in RT at 7 years ($\beta = -0.13$, $p = .04$). Accuracy and RT at 7 years were also negatively associated, but not significantly ($\beta = -0.09$, $p = .16$). These results indicate that as more children reached a threshold on accuracy at around 6 years ($M = 15.5/20$, S$D = 4.1$), the direction of the association between accuracy at Time X and RT at Time $X + 1$ becomes reliably negative. No other cross-lagged or cross-sectional associations were found.

A second cross-lagged model of accuracy and RT using the ROST at 5, 6, and 7 years (Figure 3) tested the indirect effect hypothesis. The model had an acceptable fit: $\chi^2 = 16.145$ ($df = 11$), RMSEA = 0.033, CFI = .943, SRMR = 0.037. Only one significant indirect effect was found from DCCS RT at 5 years to DCCS accuracy at 6 years through ROST accuracy at 5 years ($ab = .027$, Bootstrap 95% CI: .009 – .053), suggesting that the association between lower RT at 5 years and higher accuracy at 6 years was partly explained by working memory at 5 years. However, the direct cross-lagged path from RT at 5 years and accuracy at 6 years remained significant ($\beta = 0.13$, $p =.031$), indicating that working memory at 5 years explained 19% of the cross-lagged path from lower RT at 5 years to higher accuracy at 6 years. The indirect effect between DCCS RT at 6 years to DCCS accuracy at 7 years through ROST accuracy at 6 years was not significant (*ab* =.005; p = .62). Indeed, the direct cross-lag effect from RT at 6 years and accuracy at 7 years did not change with the inclusion of ROST to the model. Cross-lagged models with language or inhibitory control as the mediator were not conducted because the absence of concurrent correlations between DCCS RT and PPVT-R at ages 5 and 6 years or DCCS RT and Day-Night Stroop Task at age 5 years precluded their use as potential mediators. Finally, in order to test whether the association between DCCS RT at age 5 years and later accuracy at age 6 years varied as a function of inhibitory control at age 5 years, inhibitory control was entered into the models as a moderator (by creating interaction terms between inhibitory control and RT, as well as inhibitory control and mediators (WM and language). Results showed that inhibitory control did not moderate the associations between RT and accuracy on the DCCS (β = -0.04, p =.61), or the indirect effects from RT to accuracy through working memory or language (significance of interaction terms were all above $p>0.23$).

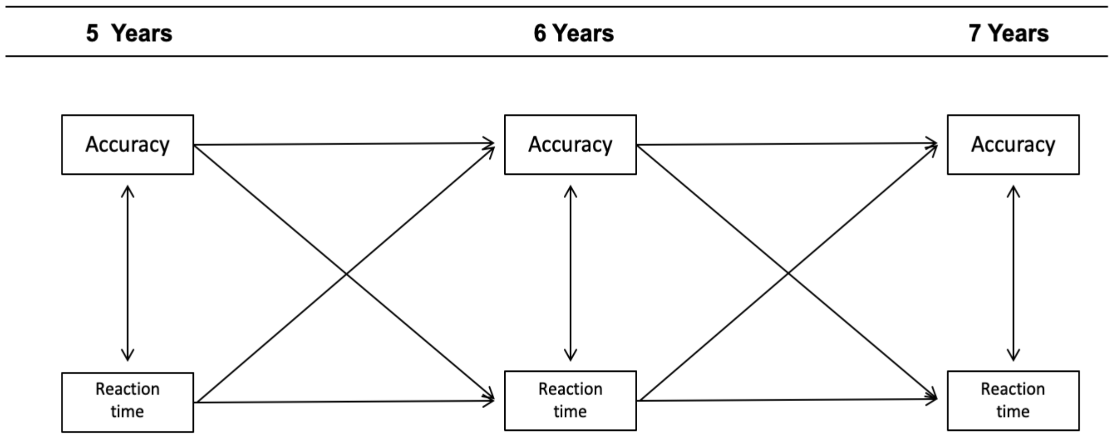

Figure 1

Longitudinal transactional model of the relation between accuracy and reaction time on the DCCS at 5, 6 and 7 years old.

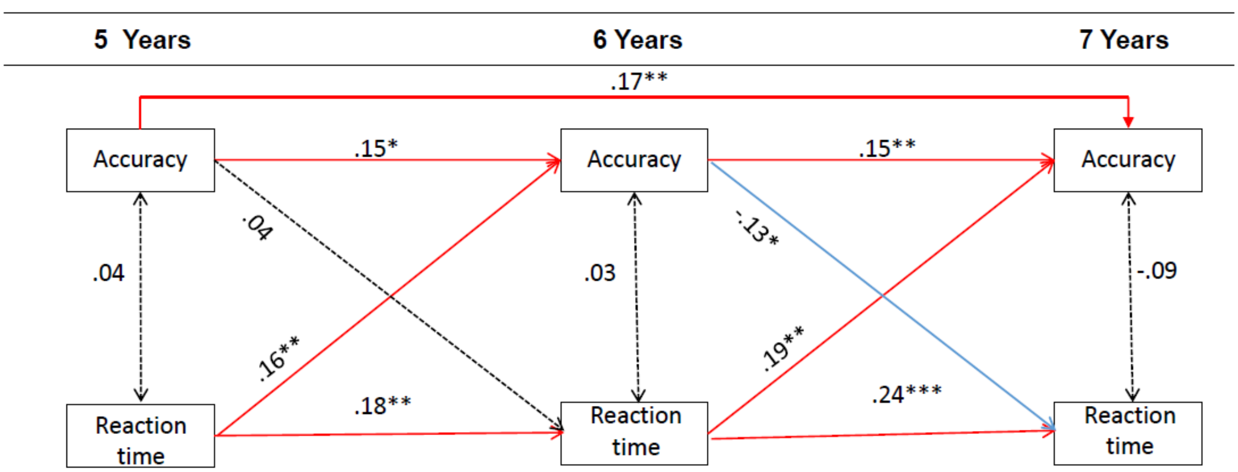

Figure 2

The cross-lagged model trials showing the longitudinal associations between the DCCS Accuracy Scored and DCCS advanced Median Reaction Time on correct and incorrect trials from 5, 6 and 7 years old.

Note: Standardized coefficients are shown; *p < .05; ** p < .01. Statistically significant paths are shown with solid lines, and non-significant paths are shown with dashed lines. Blue line = negative association. Red line = positive association. Estimation by MLR. Model fit: $\chi 2$ = 2.180(df : 3), RMSEA = .000, CFI =1.00, SRMR = .018.

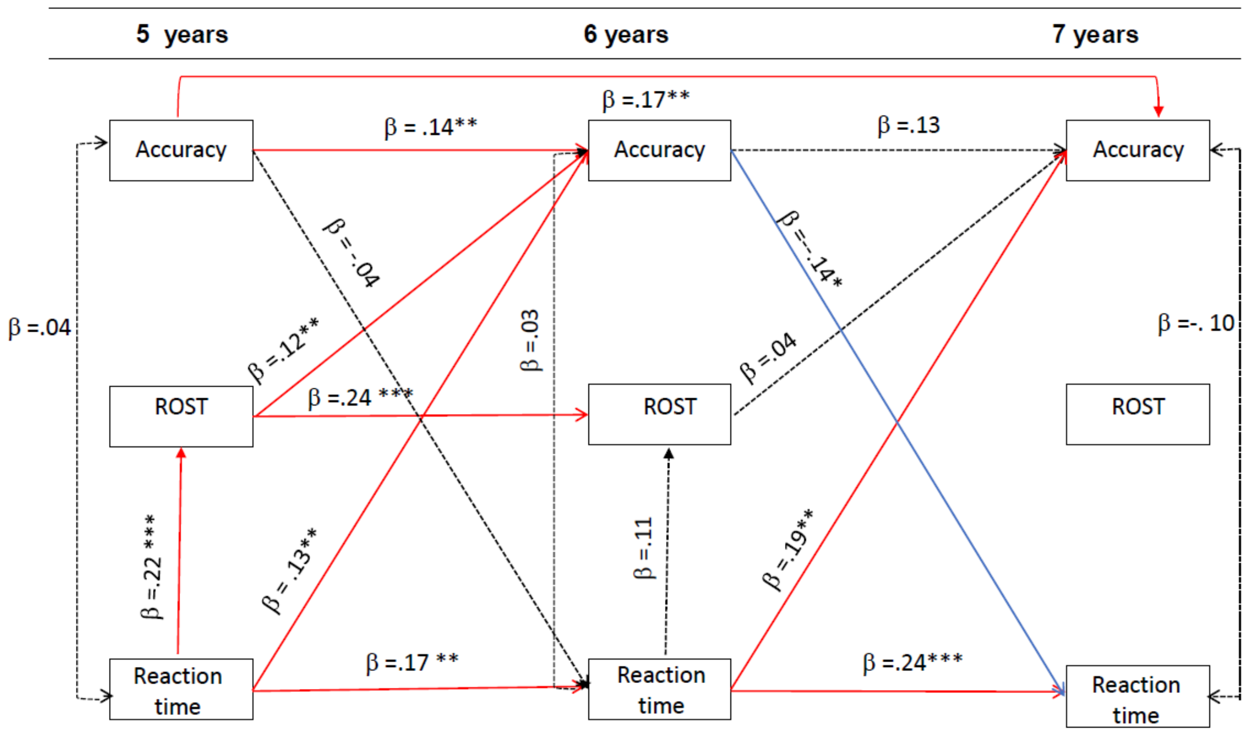

Figure 3

The cross-lagged model trials showing the longitudinal associations between the DCCS Accuracy Scored and DCCS advanced Median Reaction Time on correct and incorrect trials and ROST from 5, 6 and 7 years old.

Note: Standardized coefficients β are shown; *p < .05; ** p < .01. Statistically significant paths are shown with solid lines, and non-significant paths are shown with dashed lines. Blue line = negative association. Red line = positive association. Estimation by MLR. Model fit: $\chi2$ = 16.145 (df : 11), RMSEA = .033, CFI = .943, SRMR = .037.

Discussion

Although many cross-sectional studies have examined the development of cognitive flexibility using accuracy with preschoolers complemented later by RT at school age, there are no previous longitudinal studies examining how both indicators are related across time during this rapid period of development. To fill this gap, we examined developmental changes in the relation between both indicators using the DCCS (mixed block) across 5, 6 and 7 years using a general cross-lagged approach. This approach allowed us to test the predictive power of each indicator from one time to the next. Also, the study examined the potential roles of working memory and vocabulary as potential mediators of this developmental process exploring the role of inhibitory control at 5 years of age.

As expected, and consistent with Cepeda, Kramer, and Sather (2001) and others, there were age-related improvements in both accuracy and RT, although accuracy and RT were not related within years. However, cross-lagged panel analyses showed positive lagged associations from RT to accuracy (i.e., longer/slower RTs predicted later higher accuracy) between 5 and 6 years, and between 6 and 7 years. Additionally, as predicted, working memory, measured by the ROST, acted as a partial mediator between RT at 5 years and improvements in accuracy at 6 years, supporting the notion that slowing down and reflecting may be reliant on working memory. In contrast, and contrary to expectations, receptive vocabulary was not associated with RT, precluding assessing its role as a potential mediator between RT and accuracy over time. Similarly, as predicted, the association between RT and accuracy was not mediated by inhibitory control, as measured by the Day-Night Stroop. In contrast with our prediction, the association between RT and later accuracy did not vary as a function of level of inhibitory control.

These cross-lagged results provide longitudinal evidence about the development of cognitive flexibility, showing multi-year shifts in speed-accuracy trade-offs. The current results are consistent with both the conflict cusp and IR models. The conflict cusp model suggests a 3-phase sequence of developmental changes in the relation between accuracy and RT: (1) low accuracy/fast RT; (2) medium accuracy/slow RT; (3) high accuracy/fast RT. This sequence results from a transition from one stable state of a dynamic system to another, via a relatively rapid transition phase. Consistent with this model, we found that the youngest children had the lowest accuracy and that accuracy increased significantly across age. Although RTs did not differ significantly between 5 years and 6 years, they did between 6 and 7 years old: A change from slower to quicker responses was found between 6 and 7 years old. The lack of statistical significance in the RT mean differences across 5 and 6 years may be due to the particular age range included in the current study. Children younger than age 5 years might be more likely to make impulsive quick responses (Diamond, Carlson, & Beck, 2005). Further, the conflict cusp model also suggests that children within a given age may be at different developmental phases, and this heterogeneity in RT may be masked when comparing overall yearly means. This may account for why accuracy and RT parameters were not concurrently significantly associated with each other.

The cross-lagged associations observed in this study are also consistent with the IR model. Slowing down at age 5 or age 6 years predicted improved accuracy the following year, indicative of an increase in reflection preceding an increase in proficiency. However, as accuracy improved at age 6, it became associated with later speeding up between 6 and 7 years, consistent with an increase in the efficiency of reflection over time. Indeed, slower reaction times at Time X predicted improved accuracy between Times X and $X + 1$, and working memory at 5 years partially explained the link between slowing at 5 years and improvements in accuracy at 6 years. Although slowing down at ages 5, 6, and 7 years was related to working memory at age 7 years, there was no evidence of working memory mediating the association between slowing at age 6 years and improvements in accuracy at age 7 years. In other words, this finding is consistent with the suggestion that slowing down, reflecting and manipulating information in mind, helps children to create a complex system of rules, which allows them to behave in accordance with changing conditions (i.e., color rule with border, shape rule without border), and that working memory is needed early in this process. Once established, however, additional improvements in working memory no longer benefit later improved efficiency. Finally, the tendency for the cross-sectional beta statistic to become negative and approach significance at 7 years and the negative relation between improvement in accuracy at 6 years and improvement (faster) reaction time at 7 years, together suggest that this reflective reprocessing becomes more efficient and less costly on RT around 7 years.

Consistent with the IR model, our results support the idea that a shift from a reliance on more bottom-up influences (low accuracy/faster RT) through a transitional period (medium accuracy/slower RT) to the use of a more top-down regulation strategy (high accuracy/faster RT) happens somewhere between 5 to 7 years of age for most children on the DCCS. A shift around this period has also been found for other, related cognitive control skills, such as for reactive and proactive control (Chevalier & Blaye, 2009). Indeed, children tend to shift from using reactive to proactive control after about 5 years of age, and this transition also appears to rely on working memory (Chevalier, Martis, Curran, & Munakata, 2015; Van der Maas & Molenaar, 1992).

Limitations and Future Directions

The data described here are based on a single measure of cognitive flexibility, and on children between the ages of 5 and 7 years. Future longitudinal research using additional measures of cognitive flexibility, and examining performance across a wider age range (e.g., from 3 to 9 years) could allow for a clearer picture of accuracy and RT developments, as well as a better understanding of what might be underlying these changes.

Although we found that as predicted, working memory partially mediated the relation between RT and accuracy, receptive vocabulary did not concurrently correlate with RT, which prevented assessing it as a potential mediator between RT and accuracy over time. It is possible that receptive vocabulary is not sensitive enough as an index of the underlying language skills required for representing the (re-)formulation of complex explicit rules. A more extensive assessment of children's linguistic skills might reveal a mediating role for language.

Similarly, inhibitory control, as measured by the Day-Night Stroop, did not concurrently correlate with either of the DCCS indicators. Unfortunately, because of ceiling effects, inhibitory control was not assessed longitudinally at 6 or 7 years, so we cannot determine whether it may have had a mediator role later in the process. Further studies with other measures and a larger age range could help clarify at what ages, if any, inhibitory control is associated with accuracy and slower RT on measures of cognitive flexibility.

Further, many factors in the social environment of children may also be at play, whether at home, with peers, or at school, and particularly during the school transition. A study of such factors could help identify under which conditions cognitive flexibility is facilitated or hindered and inform prevention science.

One limitation of the cross-lagged panel-model approach taken in the current study is that it is a variable-centered approach that can confound within-person processes and more stable between-person differences (Hamaker, Kuiper, & Grasman, 2015). As DCCS studies have found variability within and between age groups (Camerota, Willoughby, & Blair, 2019), it would be useful to design future studies with shorter time lags between assessments (e.g., assessments twice a year) to disaggregate between- and within-person variation using RI-CLPM (Willoughby, Wylie, & Little, 2019). Models suggest that the sequence of developmental changes in the relation between accuracy and RT (i.e., (1) low accuracy/fast RT; (2) medium accuracy/slow RT;

(3) high accuracy/slow RT) occurs within persons. Accordingly, for within-person variation in children who have not yet entered the transition, fast RT will be associated with poor accuracy; for those just entering the transition, slow RT will be associated with better accuracy; and for those who have more fully transitioned, high accuracy will be predicted by fast RT.

Exploring inter-individual differences would also help to clarify methods for combining accuracy and RT scores, and perhaps help identify important variables responsible for initiating developmental transitions. Although methods for combining accuracy and RT scores are based on the idea that beyond some age, speed reflects cognitive flexibility better than accuracy alone, the complex relations between RT and accuracy found in the current study warrants caution with this approach. Moving ahead may require revisiting and optimizing methods for combining accuracy and RT to clarify under which conditions slower RTs are also valuable indicators of developmental changes in cognitive flexibility during this specific period of development. Future research might also usefully employ hierarchical diffusion modeling to decompose performance into separate processing components (e.g. Manning, Wagenmakers, Norcia, Scerif, & Boehm, 2021; Ratcliff & McKoon, 2008; Vandekerckhove, Tuerlinckx, & Lee, 2011).

Conclusion

This study is the first to explore the longitudinal, bidirectional relations between accuracy and RT scores on the DCCS (mixed block) at 5, 6, and 7 years with cross-lagged panel. Results of the cross-lagged panel analyses showed positive lagged associations from RT scores to accuracy between 5 and 6 years and again, between 6 and 7 years, and negative lagged associations from accuracy to RT scores between 6 and 7 years. Working memory also partly mediated the early association between RTs and accuracy. This sequence of change suggests transition phases marked by a slower reaction time before an improvement in accuracy (e.g., from perseveration to switching), and then by improved accuracy preceding increased response efficiency. Being able to maintain the relevant rules in mind may be an early step for success, as proposed by the IR model. When it comes to developmental change, the naïve assumption is to believe that children simply become "better and faster" at what they do—be it in learning to read or learning to run—and that speed and accuracy develop in tandem. However, the results of the current study suggest that the relation between speed and accuracy may be more complex. As children improve in one, they appear to take a step back in the other before catching up again. Indeed, for some areas of development, "two steps forward, one (slower) step back" might be the norm.

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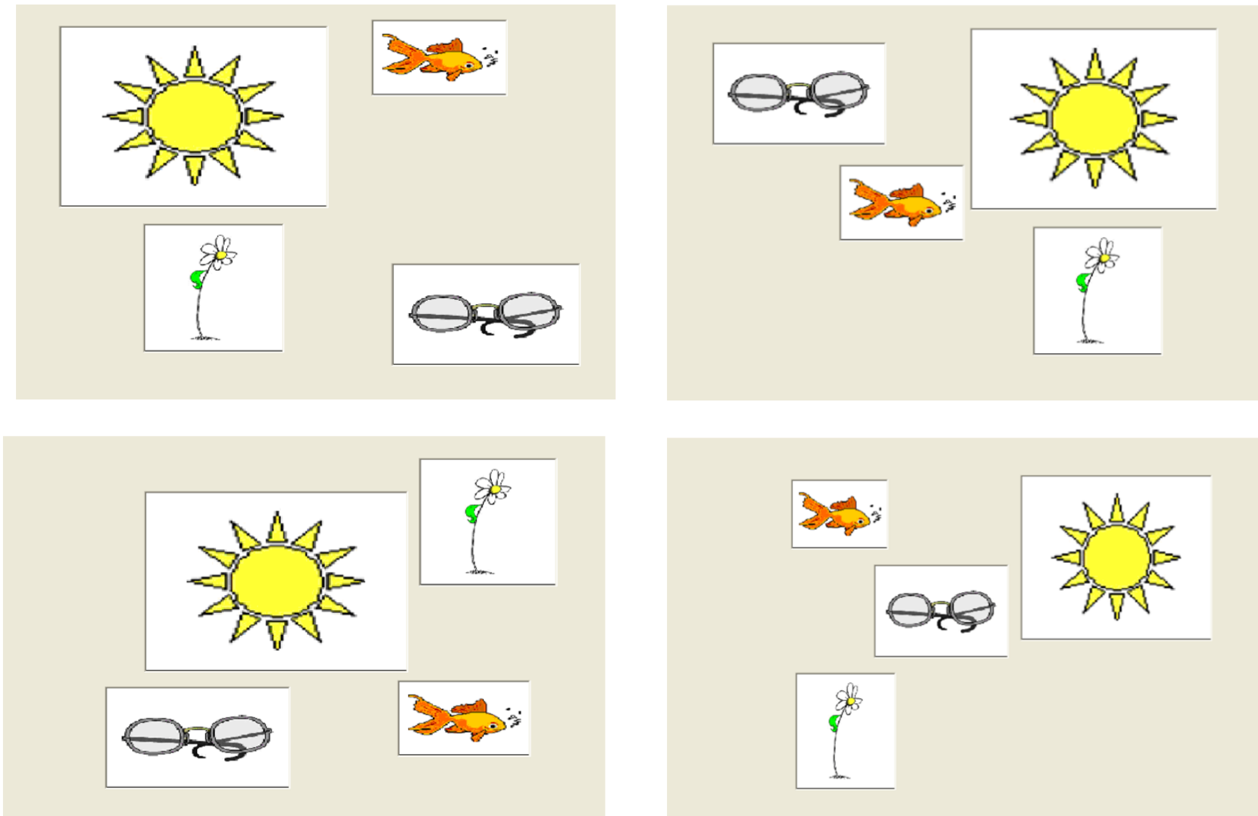
Supplemental online Figure 1



Supplemental online Figure 1.
Four arrays of images used during one of the 4 images trials of the ROST. Once the participant selected one image in an array the images were mixed on the screen to the next array. Instructions were: You will see pictures on the screen. You have to choose all of them, but only one at a time. When you'll have selected one with your finger, the pictures will get mixed on the screen. Then you select another one. Did you understand? Let's start.

Supplemental online Figures 2a and 2b.

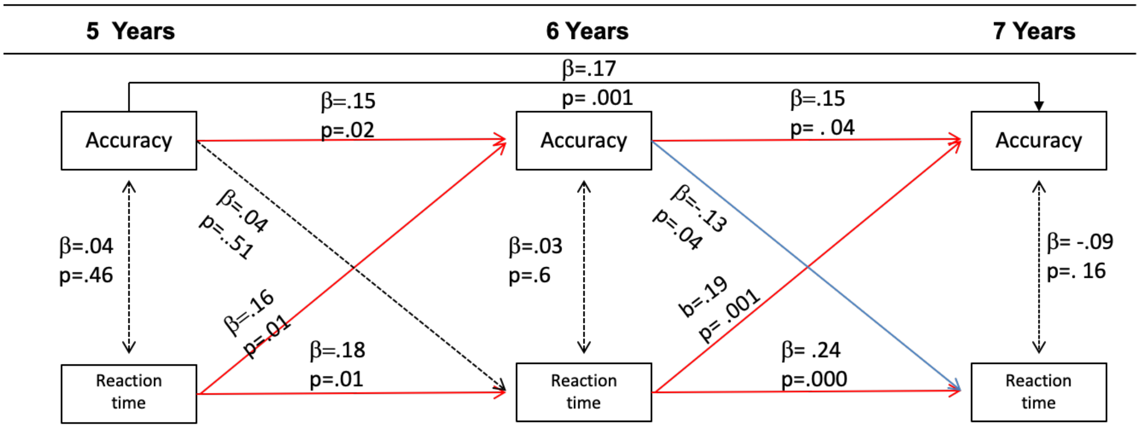


FIGURE 2a.
The cross-lagged model trials showing the longitudinal associations between the DCCS Accuracy Score and Reaction Time on correct and incorrect trials from 5, 6 and 7 years old. Standardized coefficients β are shown; *p < .05; ** p< .01.; *** p<.001. Statistically significant paths are shown with solid lines, and nonsignificant paths are shown with dashed lines. Blue line = negative association. Red line = positive association. Estimation by MLR. Model fit: $\chi2 = 2.180$ (df :3), RMSEA= 0.00, CFI= 1.00, SRMR= 0.018.

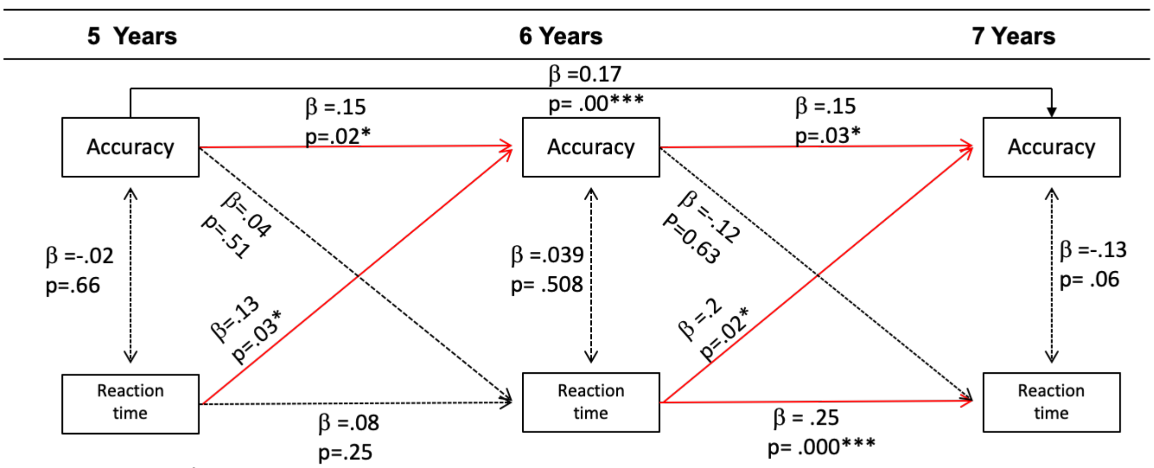


FIGURE 2b.
The cross-lagged model trials showing the longitudinal associations between the DCCS Accuracy Score and Reaction Time on correct trials from 5, 6 and 7 years old. Standardized coefficients β are shown; *p < .05; ** p< .01. Statistically significant paths are shown with solid lines, and nonsignificant paths are shown with dashed lines. Red line = positive association. Estimation by MLR. Model fit: $\chi2 = 2.071$ (df :3), RMSEA= 0.00, CFI= 1.00, SRMR= 0.018.

2.2 Deuxième article

The role of executive function at 6 years in the association between behavioral inhibition at 5 years and anxiety at 7 years.

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Objectifs spécifiques de cet article: L'objectif du deuxième article est d'examiner le rôle modérateur ou médiateur de la fonction exécutive à 6 ans dans le lien entre l'inhibition comportementale à 5 ans et l'anxiété à 7 ans. Pour tester l'hypothèse de modération, une analyse des modèles de régressions multiples des effets hiérarchiques principaux est effectuée entre l'inhibition comportementale à 5 ans et deux dimensions de la fonction exécutive (mémoire de travail et flexibilité cognitive) liées aux processus du contrôle cognitif centrés sur le but à 6 ans qui permettent de prédire l'anxiété à 7 ans.

Statut : Soumis à Research on Child and Adolescent Psychopathology

Contribution des auteurs

Émilie Dumont : Conceptualisation de l’article, analyse statistique, interprétation des résultats, rédaction des différentes sections de l’article et préparation des tableaux et graphiques.

Sophie Parent: Soutien à la conceptualisation de l’article, à l’interprétation des résultats et révision de l’article.

Natalie Castellanos-Ryan: Soutien à la conceptualisation de l’article, à l’analyse statistique et à l’interprétation des résultats et révision de l’article.

Sophie Jacques : Soutien à la conceptualisation de l’article, à l’analyse statistique et à l’interprétation des résultats et révision de l’article.

Mark H. Freeston : Soutien à la conceptualisation de l’article et révision de l’article

Philip David Zelazo : Soutien à la conceptualisation de l’article et à l’interprétation des résultats.

Jean Séguin: Soutien à la conceptualisation de l’article et à l’interprétation des résultats, aide à la rédaction, correction du manuscrit et révision de l’article.

Abstract

EF skills play a central role in the etiology and maintenance of anxiety, but it is unclear whether they act as moderators or mediators in the relation between early behavioral inhibition (BI) and later anxiety (Henderson et al., 2015; Fox et al., 2021). The current study tested two models by examining whether two EF skills (cognitive flexibility and working memory) assessed at age 6 acted as moderators or mediators in the relation between BI at 5 years and anxiety symptoms at 7 years. The sample consisted of 425 children from the Quebec Longitudinal Study of Child Development. We tested the moderation model, main and interaction effects using hierarchical multiple regression analyses and the mediation model with the product of coefficients test. Results showed that higher BI at 5 years predicted high anxiety at 7 years only at low levels of cognitive flexibility or working memory at 6 years. This suggests that high levels of cognitive flexibility or working memory at 6 years may act as protective factors. In contrast, neither cognitive flexibility nor working memory at age 6 acted as mediators in the association between BI at 5 years and anxiety at 7 years. Results support the hypothesis that goal-driven cognitive control processes act as moderators and promote adaptive functioning by dampening the effect of early BI on later anxiety.

Keywords: Behavioral Inhibition, Anxiety, Cognitive Flexibility, Working Memory, Moderation, Mediation.

The role of executive function at 6 years in the association between behavioral inhibition at 5 years and anxiety at 7 years.

Introduction

Anxiety is a normal reaction to danger. Across development, children manifest transient fears and anxiety: For example, fear of strangers typically appears between 7 and 10 months, and separation anxiety typically emerges between 12 and 18 months. Anxiety becomes maladaptive when it interferes with normal functioning and it is associated with distress (Beesdo et al., 2009). Anxiety symptoms are linked to several individual, familial, and societal consequences (Essau et al., 2000), and are the most prevalent mental health condition in children and adolescents (Ghandour et al., 2019). They are common during childhood, affecting between 15 to 20% of children, and are associated with the likelihood that children later develop anxiety disorders (Beesdo et al., 2009; Creswell et al., 2020). Specific phobias and separation anxiety disorders usually emerge in early to mid-childhood, whereas social anxiety disorders emerge later in early to mid-adolescence (Rapee et al., 2009). Moreover, although the likelihood of presenting the same anxiety disorder later in development (i.e., homotypic continuity) is considered to be low to moderate, the likelihood of developing another anxiety disorder or depression (heterotypic continuity) is very high (Beesdo et al., 2009). Hence, identifying processes that precede, promote, or attenuate this continuity is crucial.

Temperament characterized by high *behavioral inhibition* (BI) appears to be one of the main early risk factors for the development of anxiety symptoms or disorders (Degnan & Fox, 2007; Sandstrom et al., 2020). BI refers to a moderately stable temperamental trait and is defined as reactive inhibition (e.g., withdrawal) to novel stimuli including people, objects, contexts or challenging situations (Degnan & Fox, 2007). During the preschool years, BI may be manifested through fearful facial expressions, proximity seeking to caregivers, social reticence, avoidance behaviors, and a vigilant attentional style. The role of BI as a risk factor for later development of anxiety symptoms has been demonstrated in several prospective studies (Biederman et al., 2001), longitudinal studies (Chronis-Tuscano et al., 2009; Hirshfeld-Becker et al., 2007) and meta-analyses (Clauss & Blackford, 2012; Sandstrom et al., 2020). Nevertheless, about 40% of children rated highly on BI do not develop later anxiety symptoms (Van Bockstaele et al., 2021). Thus, studies are needed to clarify factors that moderate or explain the association between early BI and later anxiety symptoms.

The study of differential risk and resilience amongst children with BI, including the role of cognitive processes, is important in order to identify key factors that may contribute to different trajectories. Meta-analyses (Moran, 2016; Shi et al., 2019), longitudinal (White et al., 2011) and prospective studies (Bechor et al., 2019) suggest that executive function (EF) skills or *cognitive control* may play a central role in the etiology and maintenance of anxiety. Fox, Henderson, and colleagues (Fox et al., 2021; Henderson et al., 2015), adapted Braver's (2012) Dual-Processing model of control processes in an attempt to clarify the two cognitive control processes implicated in the different trajectories between early BI and later anxiety. Specifically, successful cognitive control was defined as the capacity to regulate thoughts and action in line with given goals and involves the right balance between the use of two distinct operating control modes: goal-driven cognitive control processes (i.e., akin to the proactive mode in Braver's (2012) model) and stimulus-driven cognitive control processes (i.e., akin to the reactive mode in Braver's (2012) model). Goal-driven cognitive control processes are characterized by a top-down cognitive mode which is activated for action planning and preparation of a future event.

According to Fox, Henderson, and colleagues, some EF skills are typically used proactively, in a goal-driven cognitive control process mode (e.g., cognitive flexibility, working memory). For example, goal-driven cognitive control processes include the use of working memory, for the maintenance of a goal during planning. Stimuli-driven cognitive control processes, in contrast, are characterized by a bottom-up cognitive mode which is activated by the characteristics of salient stimuli *after* the occurrence of an event. A number of EF skills are used reactively in a stimuli-driven cognitive control process, like inhibitory control.

Two different developmental models are proposed for understanding the role of goal-driven vs. stimulus-driven cognitive control processes in the association between early BI and later anxiety. In the first model, BI and cognitive control develop independently and EF skills act as moderators. In the second model, BI is associated with the development of EF skills, which in turn act as mediators. In the moderation model, proactive goal- or rule-driven cognitive control processes (i.e., planful mode) or reactive, stimulus-driven cognitive control processes (i.e., automatic model) affect BI children differentially. On the one hand, goal- (or rule-) driven cognitive control processes (e.g., flexibly reallocating attention away from a threatening stimulus in order to attend to other contextual information) may serve to attenuate heightened vigilance responses in BI children, thereby protecting them from developing anxiety symptoms. On the other hand, stimulus-driven cognitive control processes are believed to amplify the reactivity associated with BI, promoting passive avoidance and maintaining an attention focus toward threatening information from the environment. Because BI is hypothesized to be associated with increased detection of threat or novelty stimuli, any effort to regulate this reaction using more stimuli-driven cognitive control processes would actually potentiate, rather than decrease anxiety. That is, attempts to increase inhibitory control—which is associated with stimuli-driven cognitive control—might actually serve to selectively focus attention on threatening information to the detriment of safe information. For example, when BI children encounter a new peer, overly focusing their vigilance on possible threatening information might decrease the likelihood of initiating a conversation with that peer despite objective signs of friendliness (Troller-Renfree, Buzzell, Bowers, et al., 2019). In this first model, variations in early BI would be independent from and not associated with the tendency to prefer one mode of cognitive control over the other, but BI children would be differentially affected by the cognitive control strategies they use.

In the mediation model, both cognitive control modes (i.e., goal- or stimulus-driven control) may act as intermediate processes of change or partial mediators in the relation between early BI and later anxiety symptoms. Unlike the moderation model, the tendency and ability to use one or the other cognitive control modes would not develop independently from early BI. Instead, BI would shape the balance between stimulus-driven and goal-driven cognitive control processes in favor of stimulus-driven control processes, which in turn would increase the risk for anxiety problems. Accordingly, during early childhood, children with high BI would show enhanced detection of novelty or unfamiliar stimuli or contexts. Upon associative learning, the stimulus-driven cognitive control mode of reaction toward threat and novelty would become overgeneralized across contexts, decreasing exposure to unfamiliar stimuli increasing avoidance, and therefore reducing the practice of goal-driven cognitive control processes. BI would then be associated with poorer quality of goal-driven cognitive control processes, and higher levels of stimuli-driven cognitive control processes, both of which would promote maladaptation.

The majority of studies examining moderation or mediation models were conducted at different developmental time periods using the same longitudinal cohort (Fox et al., 2001), consisting of an initial sample of 779 four-month-old infants, 291 of which were selected based on their temperament. Three groups were selected: high negative/high motor reactive group (n = 105), high positive-high motor reactive group (n = 103) and a control group (n = 83). These children's temperament was assessed repeatedly, using early observational (at age 4 months) and questionnaire (at age 2-3 years) assessments and then regularly well into adolescence. The anxiety measures administered varied with child age: since social anxiety usually manifests itself in early adolescence, the majority of studies testing these models with younger children used measures of general symptoms of anxiety, while studies of adolescents focused on social anxiety.

Most studies testing the moderating role of cognitive control processes found that anxiety was predicted by interactions between BI and both goal-driven and stimulus-driven control, but these interactions were in opposite directions. That is, studies examining goal-driven cognitive control processes, using measures such as the AX-Continuous Performance Task (AX-CPT; (Braver, 2012)) or the Dimensional Change Card Sort (DCCS; Zelazo, 2006), found significant moderation effects such that the predictive effect of BI on later anxiety was not significant when goal-driven processes were high, but it was significant and positive when goal-driven processes were low (Troller-Renfree, Buzzell, Bowers, et al., 2019; Troller-Renfree, Buzzell, Pine, et al., 2019; White et al, 2011). For example, in one study, both goal-driven cognitive control strategies (using a cognitive flexibility task, i.e., DCCS) and stimulus-driven cognitive control strategies (using inhibitory control tasks, i.e., the Day-Night Stroop and the Grass-Snow Stroop scores) were assessed at 4 years (White et al., 2011). Anxiety was measured at age 4-5 years with the parent report form of the Child Behavior Checklist. The results showed significant interactions between BI at 2-3 years and three EF tasks at 4 years in the prediction of anxiety at age 4-5 years. As suggested by the Dual-Processing model, the effect of BI was not significant when cognitive flexibility scores were high but it was significant and positive when cognitive flexibility scores were low. In contrast, the effect of BI was not significant when inhibitory control scores were low, but it was significant and positive when inhibitory control scores were high (White et al., 2011).

There are no studies using laboratory-based tasks of EF that have explored the mediation model, although in one study based on the same longitudinal cohort from Fox et al. (2001) did support this model using parent-reported measures of cognitive control (from the Behavioral Rating Inventory of Executive Functions (BRIEF)) (Buzzell et al., 2021). Specifically, a path analysis showed a mediation effect that was significant for both EF indicators: high inhibitory control scale and low flexibility scale at 7 years both mediated the link between BI at 2 years and anxiety at 9 and 12 years. However, the BRIEF correlates poorly with laboratory-based tasks of EF (Toplak et al., 2009), thus limiting comparisons. Clearly, studies are needed to compare explicitly the potential moderating or mediating roles of cognitive control processes.

Two other issues also need further consideration. First, working memory has not been studied, even though it is featured prominently in Braver's (2012) original model, and several studies have shown that lower working memory is associated with higher anxiety (Moran, 2016). A second issue that needs to be addressed is developmental: the transition from preschool to school age appears to be a cornerstone in the development of cognitive control. A switch from stimulus-driven to goal-driven cognitive control processes has been shown during this period in longitudinal studies using the AX-CPT (Troller-Renfree, Buzzell, & Fox, 2020) or a task adapted from a task-switching test (Chevalier, Martis, Curran, & Munakata, 2015; Chatham, Frank, & Munakata, 2009). We are examining whether there is an interaction in goal-directed cognitive control, given that this has not been tested in any sample during this transition. Moreover, the specificity of each EF process has not been explored by including general verbal and nonverbal cognitive tasks as control variables. Lastly, no studies have controlled for early anxiety ratings concurrent to those of early BI.

The current study attempts to address some of these limitations by examining whether the prospective association of BI at 5 years in predicting anxiety at 7 years was moderated or mediated by goal-directed control processes across the two relevant EF domains (i.e., cognitive flexibility and working memory) at 6 years. Based on the Dual-Processing model of BI and anxiety (Fox et al., 2021), moderation and mediation models were tested, controlling for general verbal and nonverbal cognitive tasks at 6 years and anxiety at 5 years. First, based on the goal-driven cognitive control processes model, we tested whether BI at 5 years interacted with cognitive flexibility and working memory at 6 years to predict anxiety at 7 years. We expected a dampening effect of cognitive control on that association. Second, based on the mediation model, we tested whether cognitive flexibility and working memory at 6 years explained the association between BI at 5 years and anxiety at 7 years. On this account, performance on the EF tasks at 6 years was expected to partly mediate the relation between high BI at 5 years and anxiety at 7 years.

Method

Participants

Participants were part of the first cohort of the QLSCD study (Dumont & al., 2022; Jetté, Desrosiers, & Tremblay, 1997), one of the three cohorts taking part in the larger Quebec Longitudinal Project of Cognitive and Behavior Development, together with the second cohort of the QLSCD (Geoffroy et al., 2010) and the Quebec Newborn Twin Study (Thériault-Couture et al. 2023). One thousand French-speaking or English-speaking families from urban areas (the Greater Montreal and Quebec City areas) and varied socioeconomic backgrounds were randomly selected from the Québec birth registry in 1996 and invited to participate. Due to attrition and variations in participation rates the number of participants available at each time point decreased (*n* = 422 at 5 years; *n* = 315 at 6 years; *n* = 242 at 7 years). At 6 years of age, 62% of children were monolingual speakers of either French or English, 31% children spoke more than one language, and 6% children spoke more than 2 languages (MacLeod et al., 2018). All measures were administered in either French (> 90%) or English (< 10%) based on parent reports of which of these two languages was their child's preferred and/or in which they were most proficient. Language of administration on any given year was unrelated to test performance. Written informed consent was provided by parents and renewed at each follow-up. Children were assessed in their homes by trained research assistants. Age 5 testing took place in the summer before children's entrance to kindergarten.

Measures

Behavioral Inhibition (BI)

BI was assessed with selected items from a maternal report anxiety questionnaire developed to screen for anxiety disorders of early childhood (Séguin and al., 2000). The choice of selected items was based on the content similarity of the Behavioral Inhibition Questionnaire (BIQ, Bishop, Spence, & McDonald, (2003)). For this study BI included mother reports at 5 years on children's fear of unfamiliar persons and contexts across four items [i.e., In the past 12 months, how often would you say that your child: a) has avoided playing in a group with new friend, b) has cried when placed in a new situation, c) has been clinging to adults in new situations for a longer time than normal, and d) has shown fear of strangers even when encouraged by you to interact]. All items were on a three-point Likert scale (1= never, 2 = sometimes, 3 = often). Cronbach's alpha (α **=** .65**)** showed acceptable reliability. The distribution of BI scores was highly negatively skewed (z = 8.99). Because of this, and in the absence of a validated clinical cutoff, we chose to dichotomize BI at the 70th percentile in order to best capture the most elevated BI scores in this sample while retaining a sufficient large number of participants across the newly created groups (Streiner, 2002). Accordingly, a cut-off score of 7 or more (at approximately the 30th percentile) was used to create a high BI group (n = 76 participants) and a cut-off score of 6 or less was used to create a low BI group (*n* = 189 participants).

Anxiety Symptoms

Anxiety symptoms were assessed when children were 5 and 7 years by maternal ratings on the Social Behavior Questionnaire (Tremblay et al., 1991). This subscale included 5 items (e.g., In the past 6 months, how often would you say that your child has been very worried or anxious?). All items were on a three-point Likert scale (1= never, 2 = sometimes, 3 = often). This questionnaire has been used in several studies and showed good convergent and discriminant validity (Boyle, & al., 1993, Leblanc, & al., 2008). Cronbach's alpha at 5 years (α = .60) and 7 years (α = .76) showed good reliability.

The Random Object Span Task (ROST)

The ROST (Hongwanishkul, Happaney, Lee, & Zelazo, 2005) is a measure of working memory adapted for children from the Self-Ordered Pointing Task (Petrides & Milner, 1982). It assesses visual working memory using representational drawings of various sizes positioned in semi-random fashion across the screen. The positions themselves change from one trial to the next. In this version, images were presented to children on a laptop computer fitted with a touch screen. At the beginning of the task, children were given the following instruction: "You will see pictures on the screen. You have to choose all of them, but only one at a time. When you have selected one with your finger, the pictures will get mixed on the screen. Then you select a different one. Do you understand? Let's start." Choosing the same image twice results in an error. To be correct, children needed to keep in mind and update the images already selected images. There were two trials per level. The number of images to be remembered increased by 1 image for each increasing level with a minimum of 2 images and a maximum of 7 images. The test was preceded by 4 practice trials with feedback. The score consisted of the total number of correct trials.

The Child and Puppet Versions of the Dimensional Change Card Sorting task (DCCS)

To assess cognitive flexibility, the mixed-blocks variation of the child DCCS (DCCS-C) was administered at 6 years on a laptop computer fitted with a touch screen. In the current version of the task (adapted from Zelazo, 2006), participants sorted test cards depicting bidimensional pictures (i.e., orange horses and brown cups) that could be sorted by either one or the other dimension (i.e., color or shape) onto two targets that depicted an orange cup and a brown horse. In this mixed-block version, the two sorting rules changed arbitrarily on a quasi-random basis across 20 trials, as indicated by the presence or absence of a cue, in this instance a black dot. A long instruction was given at the beginning of the task and again after 10 trials: "In this game, when there is a black dot like this one, we are playing the ____ (e.g., color) game. So all the ____ (e.g., orange) pictures go here and all the ____ (e.g., brown) pictures go there. If it is ____ (e.g., orange) it goes there and if it is ____ (e.g., brown) it goes there. However, when there is no black dot we are playing the ____ (alternate; e.g., shape) game. So all….". These instructions were followed by two demonstrations and four practice trials with feedback. Before each trial, a short instruction was given: e.g., "Remember, when there is a black dot you are playing the color game and when there is no black dot you are playing the shape game." The DCCS-C was composed of 15 trials according to one dimension (i.e., the dominant dimension) and 5 trials according to the other (i.e., the non-dominant dimension) for a total of 20 trials. No feedback was provided. The total score consisted of the number of correct responses.

The puppet version of the DCCS (DCCS-P) used an error detection approach to remove motor response requirements and to ensure that children's success or failure on this task was due to goal-setting errors (flexibility), rather than a lack of response inhibitory control (Jacques et al., 1999). The procedure for the mixed blocks version of the DCCS-P was similar to the DCCS-C, except that in the DCCS-P, the research assistant manipulated a puppet who sorted the cards and children were asked to evaluate the puppet's performance on each trial. The puppet sorted 13 trials correctly and 7 trials incorrectly. The total score consisted of the evaluation of the performance of the puppet across 20 trials.

The Flexible Item Selection Task (FIST)

The FIST, which also assesses cognitive flexibility (Jacques & Zelazo, 2001), was administered at 6 years on a laptop computer fitted with a touch screen. In the auto-version of the task 3 preliminary trials (1 demo, 2 practice) were administered, followed by 9 test trials. In this version of the task four cards were shown on the screen and the participants needed to match two pairs of pictures on two different dimensions. No information was provided regarding the dimensions of interest on each trial (i.e., color, shape, or size). Children were first asked to pick 2 pictures that go together in "one way" (i.e., Selection 1), and then once a pair was selected, to pick 2 pictures that go together but, in "another way", (i.e., Selection 2). Four cards were shown, however, a fourth item a distractor item, was presented but was not to be selected as it matched the other three items only on a constant, irrelevant dimension, in other words, it did not match color, size, or shape of the other three stimuli. Its addition served only to increase the level of difficulty of the task. In this part of the task, children were not reminded of the instructions on each trial but only during the demo and practice trials. For this version, the total score consisted of a score of 0 if Selection 1 was incorrect (irrespective of Selection 2 performance), 1 for trials in which only Selection 1 was correct, and a score of 2 if and only if both Selections 1 and 2 were correct. Also, these scores were rescored into proportion correct.

The Peabody Picture Vocabulary Test-Revised (PPVT-R)

The PPVT-R or its French adaptation, the *Évaluation du Vocabulaire en Images Peabody* (EVIP; Dunn, Thériault-Whalen, & Dunn, 1993) were used to assess receptive vocabulary at 6 years in English or French-speaking participants, respectively. A series of trials each depicting four images was shown to the children. For each trial, children selected the image that they thought corresponded to the word said by the examiner. Both tests contained five training items, which were then followed by items that were presented to the children based on their age and abilities according to a standard procedure for establishing floor and ceiling items. The normative sample for the EVIP was drawn from French speakers living in Canada. Scores were standardized within each language version of the test and combined into a single receptive vocabulary index.

Block Design Subtest

Non-verbal cognition was measured at 6 years using the Wechsler Intelligence Scale for Children Fourth Edition (WISC-IV) Block Design Subtest (Wechsler, 2003). Children needed to recreate a pattern shown in a picture with blocks that have various color patterns. An accuracy score was computed from matching the pattern, taking into account time to solve the problem.

Analysis Plan

The first set of analyses examined the moderator model applied to the mixed block of the DCCS-C and DCCS-P, the FIST, and the ROST at 6 years. It was hypothesized that an interaction between level of BI at 5 years and goal-driven cognitive control processes, such that only the combination of higher BI and lower scores on the DCCS-C, the DCCS-P, the FIST or the ROST at 6 years, would predict higher anxiety at 7 years. To test whether DCCS-C, DCCS-P, FIST and ROST scores at 6 years moderated the link between BI at 5 years and anxiety symptoms at 7 years, a series of hierarchical multiple regression analyses were computed with Mplus, version 7 (Muthén, 2010). Predictors and moderators were standardized before computing interaction terms, and full information maximum likelihood (FIML) was used for missing data. In each regression predicting anxiety at 7 years, we included one predictor (BI at 5 years), one moderator (DCCS-C, or DCCS-P or FIST or ROST at 6 years), and one interaction term between predictor and moderator in the first model. In the second model, control variables were also included: anxiety at 5 years and the ROST at 6 years when the DCCS-C or the DCCS-P or the FIST were examined as moderators or the DCCS-C at 6 years when the ROST was examined as a moderator. Because EF measures are moderately correlated constructs (Miyake & al. 2020), the use of other EF measures allowed us to measure their common and unique contribution. The inclusion of anxiety at 5 years allowed us to verify if the interaction was associated prospectively with anxiety at 7 years, controlling for anxiety at 5 years. The PPVT-R and the Block-Design subtests were used as controls for verbal and non-verbal cognition.

To test if the moderator hypotheses were supported, significant interactions were plotted and decomposed: simple slope tests were computed to determine whether the combination of high BI at age 5 (categorical variable) with low cognitive flexibility or working memory at age 6 (1 SD below the mean) predicted age 7 anxiety, in contrast to a combination of high BI at age 5 with high cognitive flexibility or working memory at age 6 (1 SD above the mean).

The last set of analyses tested the mediator model, with the DCCS-C, the DCCS-P, the FIST or the ROST at 6 years, and using the product of coefficients test. This test assessed the indirect effect as the product of two regression coefficients (one linking age 6 DCCS-C or DCCS-P or FIST or ROST to age 7 anxiety and one linking age 5 BI to age 6 DCCS-C or DCCS-P or FIST or ROST). The asymmetric confidence intervals approach was used. Among other advantages, this method shows increased power and reliability in smaller samples (Mackinnon et al., 2004). In addition, models were compared to each other with indices of goodness of fit (e.g., Chi-square difference, SRMR, RMSEA, CFI, information criteria).

In all the analyses, control for the confounding effect of age was accomplished by removing variance due to age differences at time of testing. For each cognitive variable we regressed the cognitive scores on age in months at time of testing and saved the residuals. Then we added the mean of the original cognitive scores to the residuals.

Results

Descriptive statistics

The descriptive statistics for BI, DCCS-C, DCCS-P, FIST, ROST, Anxiety at 5 and 7 years, PPVT-R and Block Design tests are shown in Table 1, while Table 2 presents correlations among the main variables. At the group level the means for anxiety between 5 and 7 years appear to be similar and are also significantly and positively correlated. There was a significant positive correlation between BI at 5 years and anxiety at 5 years. BI at 5 years was also positively associated with the FIST at 6 years but was not associated with any of the other cognitive measures at that age. Anxiety at ages 5 and 7 years was not associated with any age 6 years cognitive measure. All measures of EF were significantly, positively and moderately associated with each other. PPVT and the Block Design at 6 years were significantly correlated with the DCCS-C, the DCCS-P and with the FIST at 6 years. At 6 years, the Block Design, but not the PPVT, was significantly correlated with the ROST. Significant correlations were found between sex and both FIST and ROST. In order to test that there was no difference between the models according to sex, we split the data by sex and then analyzed the table of correlations of the main factors. There were no significant differences between the two groups, except for the ROST which was significantly negatively correlated with anxiety at 7 years for boys but not for girls. Consequently, multigroup analyses were used in order to verify whether effects differed by sex for the ROST, but no sex differences were found with the Chi Square difference test (χ^2 (3, N = 422) = 3.36, p = 0.34).

Table 1 Descriptive data for all model variables

Measures	N	Min.	Max.	M.	SD.	Skewness (SE)	Kurtosis (SE)
1. BI 5 y	265	N: 189 (71.3%)	N: 76 (28,7%)	-	-	-	-
2. DCCS-C 6 y	297	3	20	15.6	3.9	-0.75 (0.14)	-0.33 (0.28)
3. DCCS-P 6 y	312	4	20	15.3	3.8	-0.62 (0.14)	-0.41 (0.28)
4. FIST 6 y	315	0.3	1.3	0.9	0.2	-0.27 (0.14)	-0.88 (0.27)
5. ROST 6 y	315	1	13	7.4	2.3	-0.07 (0.14)	-0.49 (0.27)
6. Anxiety 5 y	422	4	11	6.2	1.5	0.44 (0.12)	-0.16 (0.24)
7. Anxiety 7 y	242	4	12	6.2	1.7	0.59 (0.16)	0.14 (0.31)
8. PPVT-R 6 y	308	22	130	85.8	16.1	-0.58 (0.14)	0.67 (0.28)
9. BD 6 y	305	3	57	21.3	9.7	0.40 (0.14)	0.09 (0.28)

Note. Due to attrition, loss to follow up, and variations in participation rates, 422 participants had data available for analyses at one time point at least. However, the number of participants available decreased from one time to the next. BI = Behavioral Inhibition scale (because BI is dichotomous, % of participants for the min score (0) and max score (1) were reported); DCCS-C = Dimensional Change Card Sort Child Version; DCCS-P = Dimensional Change Card Sort Puppet Version; FIST = The Flexible Item Selection Task; ROST = Random Object Span Task; PPVT-R = Peabody Picture Vocabulary Test-Revised; BD = Block Design subtest.

Table 2

Bivariate correlation matrix for all model variables

Measures	1	2	3	4	5	6	7	8	9
1. BI 5 y	-								
2. DCCS-C 6 y	-.01	-							
3. DCCS-P 6 y	.05	.52**	-						
4. FIST 6 y	.17*	.18**	.31**	-					
5. ROST 6 y	-.08	.18**	.16**	.33**	-				
6. Anxiety 5 y	.30**	.06	.02	.06	-.06	-			
7. Anxiety 7 y	.13	.04	-.04	-.02	-.13	.44**	-		
8. PPVT-R 6 y	.10	.25**	.20**	.17**	.11	.01	-.03	-	
9. BD 6 y	.10	.17**	.26**	.30**	.20**	-.10	-.13	.33**	-
10. Sex	.10	-.01	.09	.16**	.16*	.01	.08	.03	0. 00

Note. *$p < .05$; **$p < .01$ B.I. = Behavioral scale; DCCS-C = Dimensional Change Card Sort-Child Version; DCCS-P = Dimensional Change Card Sort-Puppet Version; FIST = The Flexible Item Selection Task; ROST = Random Object Span Task; PPVT-R = Peabody Picture Vocabulary Test-Revised; Block = Block Design Subtest. Pairwise method was used for missing data.

Moderation analyses

Moderation analyses were then conducted to examine whether the interaction between BI at 5 years and EF (DCCS-C, DCCS-P, FIST, ROST) at 6 years predicted anxiety at 7 years. For each separate EF measure, we tested four statistical models: (a) the first included only the main effects of the BI and EF variables, (b) the second included a model with the main and interaction effects; (c) the third model included the main and interaction effects of BI with EF and controlled for anxiety at 5 years as a control variable; (d) a final model included the main, and interaction effects of BI with EF, controlled for anxiety at 5 years, and other cognitive variables as control to test for specificity.

Flexibility Measures: DCCS-C and DCCS-P Versions and FIST

For the first model using the DCCS-C, the main effects of BI and DCCS-C were not significantly related to anxiety at 7 years (β = .13 p = .12; β = .05 p = .60). For the second model, an interaction between BI at 5 years and the DCCS-C at 6 years predicted anxiety at 7 years (β = -.22, p = .03) (see Figure 1a). Simple slope analyses showed that the association of BI at 5 years with anxiety at 7 years was significant and positive when the DCCS-C was low (β = .68, p = .01), but not significant when the DCCS-C was high (β = -.11, p = .66), which supports the goal-driven cognitive control processes hypothesis. When anxiety at 5 years was entered in the third model as a control variable, the interaction term was attenuated slightly below significance but remained in the same direction (β = -.17, p = .07). When the other cognitive covariates (PPVT, BD, ROST) were entered in the fourth model without anxiety at 5 years, the interaction term remained significant (β = -.22, p = .02).

For the first model using the DCCS-P, the main effects of BI and DCCS-P scores were not significantly related to anxiety at 7 years (β = .13 p = .12; β = -.04 p = .60). For the second model, an interaction between BI at 5 years and the DCCS-P version at 6 years predicted anxiety at 7 years (β = -.21, p = .02) (see Figure 1b). Simple slope analyses showed that the association of BI at 5 years with anxiety at 7 years was significant and positive when DCCS-P was low (β = -.11, p = .01), but not significant when DCCS-P was high (β = .71 p = .61), which supports again the goal-driven cognitive control processes hypothesis. When anxiety at 5 years was entered in the third model as a control variable, the interaction was no longer significant but remained in the same direction (β = -.16, p = .05). When the cognitive covariates (PPVT, BD, ROST) were entered in the fourth model without anxiety at 5 years, the interaction term remained significant (β = -19, p = .03).

Finally, for the first model using the FIST, the main effects of BI and FIST scores were not significantly related to anxiety at 7 years (β = .15 p = .06; β = .02 p = .83). For the second model, the interaction between BI at 5 years and FIST at 6 years was not significant in predicting anxiety at 7 years (β = −.10, p = .22) (see Figure 1c).

Working Memory Measure: ROST

For the first model using the ROST, the main effects of BI and ROST scores were not significantly related to anxiety at 7 years (β = .11 p = .16; β = -.13 p = .10). For the second model, the interaction between BI at 5 years and ROST at 6 years significantly predicted anxiety at 7 years (β = -.19, p = .04) (see Figure 1d). Simple slope analyses showed that the association of BI at 5 years was significant and positive when the ROST was low (β = .59, p = .01), but not significant when the ROST was high (β = -.13, p = .60), which supports the goal-driven cognitive control processes hypothesis. When anxiety at 5 years was entered in the third model as a control variable, the interaction term was no longer significant but remained in the same direction (β = -.14, p = .13). When the cognitive covariates (PPVT, BD, DCCS-C) were entered in the fourth model, the interaction term remained significant (β = -.19, p = .04).

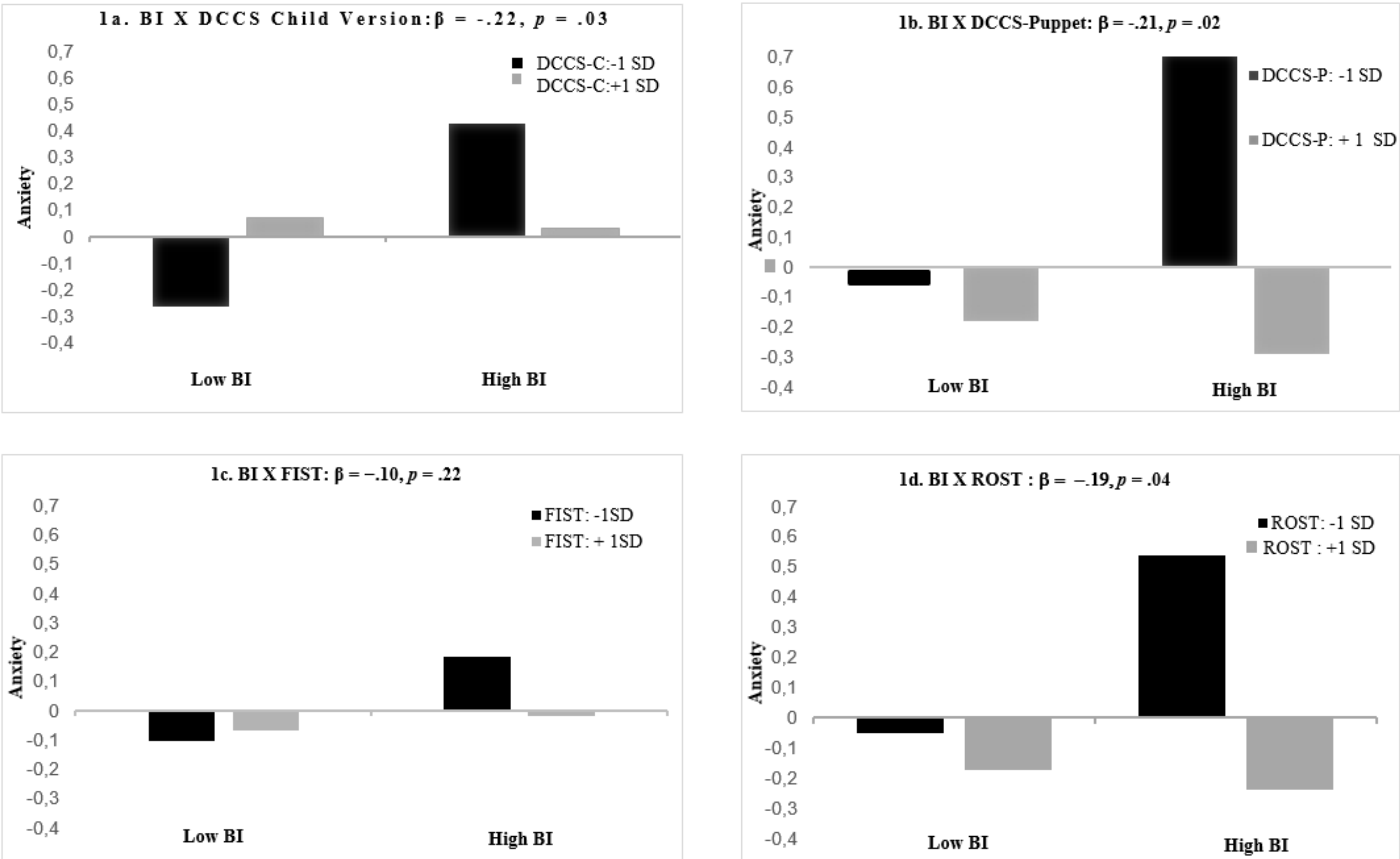

Figure 1. Age 5 BI by age 6 Executive function interaction predicting the anxiety at age 7. BI = Behavioral Inhibition scale; DCCS-C= Dimensional Change Card Sort Card Sort Child version; DCCS-P= Dimensional Change Card Sort Card Sort Puppet version; FIST = The Flexible Item Selection Task; ROST = Random Object Span Task.

Indirect effect analyses

The last set of analyses tested the potential mediating role of DCCS-C, DCCS-P, FIST and ROST at 6 years between BI at age 5 years and anxiety at age 7 years. The absence of correlations between BI at 5 years and the DCCS-C and DCCS-P as well as the ROST at 6 years precluded their use as potential mediators according to causal steps logic (Baron & Kenny, 1986). Thus, only the indirect effect of the FIST was tested, using the product of coefficients test and asymmetric confidence intervals. Results show that the indirect effect between BI at 5 years and anxiety at 7 years via FIST at 6 years was not significant (95% CI [-.04, .01] $ab = -.01$, $p = .62$).

DISCUSSION

This prospective study tested whether the prediction of anxiety symptoms at 7 years from BI at 5 years would be moderated or mediated by two EF skills associated with proactive, goal-driven cognitive control processes at 6 years: (a) cognitive flexibility measured with the child and puppet versions of the DCCS, and the FIST; and (b) working memory measured with the ROST. Two main hypotheses were tested. First, according to the Dual-Processing model of the development of BI and anxiety (Henderson et al., 2015; Fox et al., 2021), it was hypothesized that goal-driven cognitive control processes would act as moderators: early BI would significantly predict later anxiety at low but not at high levels of goal-driven cognitive control processes. Second, goal-driven cognitive control modes could act as mediating mechanisms, explaining continuity between early BI and later anxiety symptoms.

The first hypothesis concerning moderation was generally supported by the data. Our results showed that BI at 5 years interacted with cognitive flexibility and working memory at 6 years to predict anxiety at 7 years. The results support the hypothesis that cognitive flexibility and working memory attenuate the risk conferred by early BI to develop later symptoms of anxiety. A previous study with the DCCS-C at 4 years interacted with BI to predict anxiety at 4-5 years (White et al., 2011). In the present study we extended these findings in two ways. First, the hypothesis was tested using two versions of the DCCS, Child and Puppet—the latter of which had minimal response inhibition requirements—at 6 years in the prediction of anxiety at 7 years. Second, the hypothesis was also tested for another goal-driven cognitive control process, working memory at 6 years. Although working memory is a main component of Braver's (2021) Dual Processing model, its possible interaction with early BI in predicting later anxiety had never been examined. As such, our finding extend Henderson et al.'s (2021) model to another important EF dimension. Moreover, our study is also the first to control for one EF skill in the examination of the role of another EF skill in the relation between BI and anxiety. EF skills are known to be moderately correlated (Lehto et al., 2003; Miyake et al., 2000) and could act as confounders. The significance of the moderation effect for each EF skill, over and above the contribution of the other EF skills, suggested that the dampening effect of cognitive flexibility and working memory are distinct from each other. However, when anxiety at 5 years was entered in the models as a control variable, the interaction term was attenuated slightly below or near the significance level. This finding indicates that the protective contribution of goal-driven cognitive control could emerge before 5 years, which is consistent with White et al.'s (2011) findings with 4-5-

year-olds whereas BI at 24 months interacted with DCCS at 48 months years to predict an average of anxiety at 4 and 5 years.

In contrast to the DCCS-C and DCCS-P, BI did not interact with our third measure of cognitive flexibility: the FIST. Given the fact that the FIST was reasonably well correlated with other EF and cognitive tasks, this result was not anticipated. However, inspection of Figure 1 indicates that the overall pattern of results was similar to that of the other measures, although much more attenuated. One possible explanation may be that the FIST required both stimulus- driven AND goal-driven cognitive control, which cannot be readily disentangled. For example, unlike the DCCS where the dimensions of interest are explicit, on the FIST, relevant stimulus dimensions change from trial to trial. Consequently, participants cannot prepare in advance, at least in the early trials, and must act when the stimuli appear, which characterizes stimulus-driven cognitive control processes. As stimulus-driven processes would be expected to increase anxiety later in children with earlier high BI scores, they might partly obscure the contribution of goal-driven cognitive control processes in the developmental association between early BI and later anxiety.

The second hypothesis concerning mediation was not supported by the data. BI was not associated with any of our goal-driven cognitive control tasks. This finding is consistent with studies that have shown that early BI was not associated with goal-directed cognitive control (i.e., the DCCS) to predict later anxiety (White et al., 2011). These findings suggest that EF develops independently from BI at least in this age range. In contrast, a recent study supported the mediating role of goal- and stimulus-driven cognitive control processes with slightly older children, aged between 9 and 12 years old

(Buzzell et al., 2021). As anxiety symptoms are known to increase with age (Steinsbekk et al., 2022), the role of cognitive control variables may differ according to age, acting as moderator at some ages and mediators at other ages.

In sum, the transition period from preschool to school age is characterized by rapid changes in cognitive control processes and symptoms of anxiety. In this context, studying the longitudinal relations among temperament, anxiety, and cognitive control processes will be important to better understand how these developmental changes also affect the dynamic interplay between these child characteristics.

Practical implications

According to a recent meta-analysis, CBT interventions decreased anxiety symptoms compared to control conditions (Rith-Najarian et al., 2019). However, reduction of anxiety symptoms in preschool children high on BI was smaller than for those lower on BI (Howes Vallis et al., 2020). There is thus evidence that a universal approach to prevent anxiety may not be the most effective practice for children with high anxiety symptoms. A suggested alternative would be to develop a selective, more personalized, approach. For example, Howes, Vallos and colleagues (2020) recommended focusing preventive interventions on “ultra at-risk” groups formed by combining several risk factors. Such an approach usually targets individuals with two risk factors: high BI and having a parent with anxiety disorders. Our results suggest that one might also consider children who have difficulties with their goal-driven cognitive control processes. Further, our results suggest that the inclusion of intervention components, such as EF training, that target goal-driven cognitive control processes in particular could benefit children who are high on BI. Supporting the development of these cognitive control processes might be particularly beneficial for anxious children who also experience elevated BI as a way to help them regulate their attention away from stimuli that they perceive as threatening. Thus, EF training could help these anxious kids regulate their first reactions, which would in turn help them decrease avoidance and get involved in real life activities (e.g., in social play activities).

Strengths, Limitations, and Avenues for Future Research

Strengths of the current study include the use of multiple reliable laboratory measures of proactive, goal-driven cognitive control processes, including the addition of working memory, and an assessment of change in anxiety symptoms over time in an understudied age range. This allowed replication and extension of previous findings with a new prospective community cohort and not a sample selected for BI, using a different age range, and additional control measures. Two limitations of the current study should also be acknowledged. First, we did not have any task measuring stimulus-driven cognitive control processes in this age range. We thus could not test the hypothesis suggested by Henderson and colleagues (2015) that high stimulus-driven cognitive control abilities might exacerbate the tendency for high BI children to demonstrate anxiety. Another limitation was the use of the same informant (parent questionnaire) for the assessment of anxiety and BI. Parents could be unaware of the internal thoughts and feelings of their children or could be biased by their own mental health (Freidl et al., 2017). Further, use of the same informant may create a problem of shared-method variance (Homburg, Klarmann, & Totzek, 2012). This limitation was somewhat attenuated by the fact that these measures were collected across different ages. Future research should attempt to include varied sources of ratings (e.g., other informants, or an observational procedure for ratings of BI).

In sum, anxiety is associated with significant individual, family, social, and economic costs, including academic failure, substance abuse and morbidity (AIHW, 2019). Following Erasmus' proposition that prevention is better than cure, our study focused on identifying processes that precede, promote, or attenuate the occurrence of anxiety disorders. Although our results did not support the mediational hypothesis, they very clearly supported the protective role of goal-driven cognitive control processes in the link between BI and anxiety as proposed by Henderson et al. (2021). Our results thus extend research suggesting that a combination of risk factors need to be considered when screening preschoolers who are most likely to develop anxiety disorders, specifically, those with high early BI who also show low abilities in goal-directed cognitive control processes. While previous studies had only focused on cognitive flexibility, our study was the first to show that high working memory could also attenuate the risk to develop anxiety in high BI children. Overall, our results thus highlighted the relevance of helping high BI children develop better goal-driven EF skills in order to prevent anxiety.

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3 Discussion générale

Selon Blair et Raver (2015), l'autorégulation est un système composé de cinq niveaux hiérarchiques réciproquement reliés : cognitif, émotionnel, comportemental, physiologique et génétique. L'objectif principal de cette thèse était d'examiner, pendant la transition préscolaire-scolaire, le développement de trois de ces cinq niveaux du système régulatoire : cognitif, comportemental et émotionnel. Le premier article examinait le développement cognitif, spécifiquement la flexibilité cognitive pendant la transition préscolaire-primaire soit à 5 ans, 6 ans et 7 ans et le deuxième article explorait la relation entre ces trois niveaux, en étudiant le tempérament de type inhibé à 5 ans et les fonctions exécutives à 6 ans pour prédire l'anxiété à 7 ans.

3.1 Résumé des résultats et apports de la thèse

Selon Blair et collègues, l'enfant serait prêt à aller à l'école lorsque ses niveaux cognitifs seraient assez développés pour contrôler ses niveaux émotionnels et comportementaux afin de lui permettre de s'engager dans des activités d'apprentissage. Le but des deux études aborde le développement de la fonction exécutive pendant cette transition préscolaire-scolaire. L'évaluation de la fonction exécutive pendant la période de transition entre l'âge préscolaire et scolaire est un défi méthodologique, car les outils servant à l'évaluer doivent répondre à trois composantes : la nouveauté, la complexité et l'intégration de l'information (Anderson et al., 2008). Pour y arriver, l'indice d'exactitude est habituellement utilisé à l'âge préscolaire, puis à l'âge scolaire, le temps de réaction ou la combinaison des deux indicateurs sont nécessaires pour pallier l'effet plafond souvent retrouvé avec l'indicateur d'exactitude. De plus, les modèles théoriques et les études transversales suggèrent la présence d'un compromis entre l'exactitude et la vitesse pendant cette transition. L'exactitude est privilégiée au prix d'une réduction du temps de réaction (c.-à.-d. un ralentissement) (Diamond et al., 2007). Toutefois, la compréhension de ce point de coupure est limitée par le manque d'études longitudinales qui examinent ces deux indicateurs pendant la transition. Le premier objectif de la première étude était d'explorer les liens longitudinaux et bidirectionnels entre les indices d'exactitude et de temps de réaction du DCCS à 5 ans, 6 ans et 7 ans en utilisant des analyses à décalage croisées. L'utilisation de ce type d'analyse dans l'étude du développement de la fonction exécutive est novatrice, car c'est la première étude qui utilise ce type d'analyse en intégrant les deux indicateurs de la flexibilité cognitive. Cet aspect novateur a permis de comprendre la séquence du développement de la flexibilité cognitive, mais également de mieux saisir les mécanismes sous-jacents à son développement. Cette étude est la première à avoir démontré des associations décalées croisées positives significatives. Ces associations sont les suivantes :

- un temps de réaction plus lent à 5 ans prédisait une meilleure exactitude à 6 ans et ce patron s'est répété entre 6 et 7 ans;
- une meilleure exactitude à 6 ans prédisait un temps de réaction plus rapide à 7 ans.

Ces résultats appuient la séquence de développement suggérée par le modèle des Conflits Cusp développé par van Bers, Visser, van Schijndel, Mandell, et Raijmakers, 2011, (traduction du « conflict cusp model » en anglais, voir introduction du premier article) : (1) exactitude faible/temps de réaction rapide; (2) exactitude modérée/temps de réaction ralenti; (3) exactitude élevée/temps de réaction rapide. L'étude a également examiné le potentiel médiateur de la mémoire de travail et du vocabulaire dans le développement de la flexibilité cognitive. Les analyses ont démontré le rôle de médiateur partiel de la mémoire de travail entre le temps de réaction à 5 ans et l'exactitude à 6 ans. Ces résultats soutiennent le modèle itératif (Zelazo, 2015) en démontrant que le développement des dimensions de la fonction exécutive, dont la flexibilité, suit un processus itératif défini par un ralentissement, une réflexion qui inclut la reformulation de règles explicites et le maintien de ces informations en tête (mémoire de travail). Le développement de la flexibilité cognitive est possible par la réflexion et la formulation de l'utilisation de règles de plus en plus complexes gardées en mémoire (p. ex. : dans le DCCS mixte l'enfant doit être capable de formuler deux règles : les cartes avec un point noir devront être placées en fonction de la forme, tandis que les cartes sans point noir devront être placées en fonction de la couleur). L'inhibition cognitive à 5 ans n'était associée ni à l'exactitude ni au temps de réaction de la flexibilité. Bref, l'étude a démontré que la transition préscolaire-scolaire est une période sensible du développement de la flexibilité.

Par ailleurs, selon le modèle de régulation de Blair, le niveau supérieur comprenant la fonction exécutive permet de réguler par un mécanisme de haut-en-bas les réponses comportementales réactives et émotionnelles telles que l'inhibition comportementale et l'anxiété. De manière plus spécifique, Henderson et al., (2015) et plus récemment par le même groupe de chercheurs (Fox et al., 2021) suggèrent différents modèles afin de mieux comprendre le rôle des processus du contrôle cognitif, incluant la fonction exécutive, dans l'association entre le tempérament de type inhibé et l'anxiété. Ainsi, le deuxième article visait à examiner deux de ces modèles en évaluant le potentiel rôle médiateur ou modérateur de deux fonctions exécutives: la flexibilité et la mémoire de travail dans la possible relation entre l'inhibition comportementale à 5 ans et l'anxiété à 7 ans. Trois aspects novateurs peuvent être dégagés de cet article. Le premier aspect novateur de cette seconde étude réside dans l'inclusion de la mémoire de travail dans l'étude de la relation entre l'inhibition comportementale et l'anxiété à l'âge préscolaire. En effet, d'autres dimensions de la fonction exécutive ont été étudiées dans la relation BI et anxiété, mais la mémoire de travail n'avait jamais été incluse dans ces analyses. Deuxièmement, la flexibilité cognitive a déjà été étudiée dans cette relation entre l'inhibition comportementale et anxiété, mais jamais pendant la transition préscolaire-primaire. Troisièmement, l'inclusion des variables contrôles telles que d'autres fonctions exécutives a permis de clarifier le rôle unique celles-ci dans cette relation.

Les résultats suggèrent que la flexibilité cognitive, évaluée par l'indice de d'exactitude du DCCS (versions enfant et marionnette) et la mémoire de travail, évaluée par le ROST, agissent comme variables modératrices, c'est-à-dire que l'inhibition comportementale à 5 ans est positivement associée à des symptômes d'anxiété à 7 ans, mais seulement lorsque les enfants montrent une flexibilité cognitive ou une mémoire de travail faibles à 6 ans. L'inhibition comportementale et l'indice du temps de réaction du DCCS version enfant n'interagissent pas de manière significative pour prédire l'anxiété. De bons niveaux de flexibilité cognitive ou de mémoire de travail à 6 ans constitueraient un facteur protecteur du développement de l'anxiété tel que suggéré par la théorie de Henderson et al., (2015) (Fox et al., 2021).

Les résultats des deux études génèrent un nouvel appui pour le modèle intégratif hiérarchique de l'autorégulation de Blair (Blair et Ku, 2022). D'une part, la première étude confirme le développement de la flexibilité cognitive pendant la transition préscolaire-scolaire permettant, entre autres, un meilleur contrôle sur le comportement et les émotions. Des études supplémentaires sont nécessaires afin de confirmer l'hypothèse de Blair et collègues suggérant que ce meilleur contrôle permet à l'enfant de s'engager dans les activités d'apprentissage. D'autre part, les résultats de la deuxième étude confirment l'influence des mécanismes de haut en bas sur l'adaptation socio-affectif. Les fonctions exécutives aident à réguler les réactions automatiques des niveaux inférieurs tels que l'inhibition comportementales pour prévenir l'anxiété à 7 ans.

3.2 Implications pour la recherche future

Deux suggestions pour la recherche future peuvent s'appliquer aux deux articles. Une première suggestion viserait à étendre l'âge d'étude des processus développementaux de l'autorégulation identifiés dans cette thèse. D'une part, la fenêtre d'âge étudiée (5 ans, 6 ans et 7 ans) ne permet pas d'explorer les processus développementaux en amont. Effectivement, en lien avec le premier article, avant de pouvoir réussir le DCCS en blocs mixtes, l'enfant doit être en mesure de réussir des tâches plus simples de flexibilité telles que le DCCS bloc standard (contrairement aux blocs mixtes, où les deux règles de tri changent quelquefois de manière aléatoire, la règle de tri ne change qu'une fois dans le DCCS bloc standard). La présente étude ne permet pas d'étudier si la séquence [1-exactitude faible/temps de réaction rapide; 2- exactitude modérée/temps de réaction ralentie; 3- exactitude élevée/temps de réaction rapide] s'applique également aux premières étapes du développement de la flexibilité ni s'il y a d'autres mécanismes en jeu tels que l'inhibition cognitive. L'inhibition cognitive à 5 ans n'était reliée ni aux indices de performance du DCCS, ni au ralentissement, ni à l'exactitude. Cependant, il a été démontré dans la littérature que l'inhibition cognitive était reliée au DCCS standard à 2 ans et demi (Rennie et al., 2004). Par conséquent, il serait pertinent de reproduire l'étude pour le DCCS standard entre 2 ans et 5 ans en examinant le rôle de la mémoire de travail et de l'inhibition cognitive dans le développement de la flexibilité cognitive.

De plus, tel que suggéré par Blair, il serait intéressant d'examiner si le développement des niveaux supérieurs de la régulation telle que la flexibilité cognitive est influencée par les niveaux régulatoires inférieurs. Par exemple, est-ce que la sensibilité au stress viendrait influencer son développement?

En lien avec le deuxième article, deux suggestions de recherches futures appuient l'importance d'étendre l'étude des processus développementaux de l'autorégulation en amont. D'une part, l'inclusion de l'anxiété à 5 ans comme variable contrôle dans le modèle d'interaction a permis de voir qu'une partie du mécanisme était déjà établi avant 5 ans, car les interactions entre le tempérament inhibé et le DCCS-E ainsi que le tempérament inhibé et le ROST étaient au-dessus du seuil de signification (DCCS-E, $p = .07$; ROST, $p = .13$) et sur le seuil de signification pour l'interaction entre le tempérament inhibé et le DCCS-M ($p = .05$). White et al., (2011) ont démontré que l'interaction entre l'inhibition comportementale à 24 mois et le DCCS-C à 48 mois prédit l'anxiété à 4 et 5 ans telle qu'évaluée par le CBCL. Cependant, ils n'ont pas contrôlé pour l'anxiété à 48 mois et ils n'ont pas non plus évalué le rôle de la mémoire de travail. Il serait donc intéressant d'examiner si ce mécanisme est présent très tôt dans la vie. Notons que le CBCL peut évaluer le niveau d'anxiété dès 18 mois.

La seconde suggestion pour la recherche future tirée des conclusions des deux études serait d'étudier le rôle du contexte, spécifiquement le rôle du soutien à l'autonomie, dans le développement de l'autorégulation en général et en particulier de la flexibilité cognitive et de l'interaction entre l'inhibition comportementale et la fonction exécutive dans la prédiction de l'anxiété. Le soutien à l'autonomie parentale est défini par l'ajustement de l'aide promulgué par le parent en fonction du niveau d'habileté de l'enfant lui permettant de progresser graduellement vers l'indépendance (Meuwissen et Carlson, 2019). Ainsi, selon le domaine étudié, tels que la fonction exécutive ou la régulation de l'anxiété, le parent ne fait pas à la place de l'enfant mais l'accompagne dans l'apprentissage de la compétence. Le soutien à l'autonomie a été associé positivement avec l'autorégulation dans des études transversales (Karreman et al., 2006; Lerner et Grolnick, 2020; Obradović et al., 2021), une méta-analyse (Karreman et al., 2006) et une étude expérimentale (Meuwissen et Carlson, 2019). De plus, une méta-analyse (Valcan et al., 2018) et des études longitudinales (Distefano et al., 2018; Helm et al., 2020; Hughes et Devine, 2019) appuient la relation prédictive entre le soutien à l'autonomie et le développement de la fonction exécutive et une seconde méta-analyse appuie l'association entre le soutien à l'autonomie et l'anxiété à l'enfance (McLeod et al., 2007).

Selon le modèle de régulation de Blair, les mécanismes régulatoires tant de bas en haut que de haut en bas sont dépendants du contexte. Par exemple, l'environnement insécure incluant peu de soutien du parent est associé à une réponse réactive. Un stress aigu peut impacter la régulation de haut en bas de la mémoire de travail (dépendante de l'hippocampe préfrontal), mais n'a pas d'influence sur la mémoire procédurale, qui elle fait l'objet d'une régulation de bas en haut (Frankenhuis et al., 2020; Leonard et al., 2015). À l'inverse, un environnement sécure incluant le soutien du parent est associé à une réponse réfléchie, dont le développement optimal de la fonction exécutive (Bernier et al., 2010; Distefano et al., 2018; Hughes et Devine, 2019).

À titre d'exemple, Bernier et al., (2010) ont évalué la contribution de trois comportements parentaux : le soutien à l'autonomie (le fait d'engager un processus d'étayage, d'encourager l'enfant à poursuivre son but, de suivre le rythme de l'enfant afin qu'il ait un rôle actif), la sensibilité maternelle (le fait de repérer les signaux de détresse de l'enfant et d'y répondre) et la lecture de l'esprit (la capacité de comprendre et l'état affectif de l'enfant) sur le développement de trois dimensions de la fonction exécutive: le contrôle inhibiteur, la mémoire de travail et la flexibilité entre 18 et 24 mois. Par l'entremise d'analyses statistiques multiniveaux, les chercheuses ont démontré que seul le soutien à l'autonomie demeure un prédicteur statistiquement significatif des performances aux tâches de la fonction exécutive après que le fonctionnement cognitif général de l'enfant et le niveau d'éducation de la mère aient été contrôlés. Ces résultats ont été reproduits par deux autres études longitudinales incluant des enfants d'âge préscolaire (Bibok et al., 2009; Hughes et Ensor, 2011). De plus, un groupe de chercheurs a démontré que le soutien à l'autonomie était une variable médiatrice entre la fonction exécutive du parent et celle de l'enfant âgé entre 3 et 5 ans (Distefano et al., 2018). Ce facteur parental n'est pas à sous-estimer, car il est un facteur de risque important du développement de l'anxiété (Emerson et al., 2019; Wei et al., 2017; Yaffe, 2021).

La méta-analyse de McLeod et al., (2006), qui inclut des enfants et des adolescents, établit que le soutien à l'autonomie est le principal déterminant parental dans le développement de l'anxiété excessive, avec une taille de l'effet considérée comme large. Les auteurs définissent le soutien à l'autonomie comme la sollicitation de l'opinion et des choix de l'enfant, indépendamment de ceux du parent. Les autres comportements des parents sont associés à une taille de l'effet moindre. Par exemple, la chaleur (c.-à-d. l'interaction basée sur un affect positif) obtient une taille de l'effet considérée comme petite. L'étude longitudinale de (Ginsburg et al., 2005) a démontré que le niveau de critique élevé et le faible encouragement à l'autonomie à 5,8 ans sont associés significativement à des symptômes anxieux à la fin de l'enfance (septième année du primaire) chez les parents anxieux seulement. Toutefois, une méta-analyse, qui inclut des enfants d'âge préscolaire, ne soutient pas l'association entre le soutien à l'autonomie et le développement de l'anxiété pendant cette tranche d'âge (Möller et al., 2016). Des études supplémentaires sont nécessaires afin d'éclaircir ce lien entre le soutien à l'autonomie et le développement de la régulation émotionnelle dont l'anxiété.

Les écrits scientifiques relevés suggèrent l'importance du soutien à l'autonomie dans le développement de la fonction exécutive et de l'anxiété. Le lecteur doit par ailleurs demeurer prudent, car certaines études emploient des définitions du soutien à l'autonomie se référant à des théories différentes (Soenens et Vansteenkiste, 2010)) et des outils de mesure différents. Par exemple, Bernier et al., (2010) incluent une composante motivationnelle (renforcement) et cognitive (étayage) à la définition du soutien à l'autonomie, alors que Wei et al., 2017 définissent l'autonomie comme l'utilisation de style parental démocratique et non coercitif. De plus, les études rapportées dans la méta-analyse de McLeod, et al. (2006) s'appuient généralement sur des questionnaires auto-rapportés, alors que ce type de mesures est souvent limité car souvent biaisé (c.-à-d. que le parent anxieux a tendance à surestimer ses compétences parentales, alors que l'enfant anxieux a tendance à déprécier les compétences parentales) (Ginsburg, et al., 2004; (Rapee, 1997)). En bref, la seconde suggestion pour la recherche future est d'étudier le rôle du contexte, dont le soutien à l'autonomie dans le développement de la flexibilité et de la relation entre l'inhibition comportementale, les fonctions exécutives et l'anxiété.

En somme, l'amplitude des conséquences des atteintes de la FE et de l'anxiété chez les enfants ayant une inhibition comportementale appelle à la clarification de la relation entre ces deux phénomènes à l'enfance au développement d'intervention efficace centrée sur les facteurs de risque et de protection, dont les compétences parentales telles que le soutien à l'autonomie.

3.3 Implications pour la pratique psychoéducative

La pratique psychoéducative repose sur l'évaluation et l'intervention de l'interaction entre les capacités personnelles et les opportunités environnementales pour répondre aux défis adaptatifs (Daigle et al., 2021). La transition préscolaire- primaire est l'un des défis d'adaptation importants chez l'enfant. Le deuxième article met en évidence l'importance de cibler la fonction exécutive chez les enfants ayant un tempérament inhibé afin de prévenir l'anxiété et de favoriser l'adaptation lors de cette transition. De plus, les résultats du premier article suggèrent qu'il est important d'introduire des stratégies pour améliorer la mémoire de travail, mais également de favoriser un soutien qui met l'accent sur la réflexion (ralentir, maintenir active les informations dans la mémoire de travail). À cet effet, quelques interventions prometteuses ciblant les capacités de l'enfant (c.-à-d. le développement de la fonction exécutive par la remédiation cognitive) ou le contexte environnemental (p. ex. : le soutien à l'autonomie chez les adultes significatifs de l'enfant) pour répondre au défi adaptatif qu'est la transition préscolaire-primaire ont montré des résultats prometteurs.

D'une part, le psychoéducateur peut cibler directement la fonction exécutive par la remédiation cognitive. La remédiation cognitive s'inscrit habituellement par des programmes informatiques ou la pratique de tâches (Hermida et al., 2015) en ciblant une dimension de la fonction exécutive comme la mémoire de travail. La complexité du jeu ou de la tâche augmente en fonction des réussites du participant. L'augmentation de la complexité est un des éléments clés pour voir des effets. Une méta-analyse (Sala et al., 2018) sur le transfert rapproché (p. ex. : les résultats des études sur l'entraînement de la mémoire de travail montrent une amélioration sur des tâches mesurant la mémoire de travail) et éloigné (p. ex. : les résultats des études sur l'entraînement de la mémoire de travail montrent une amélioration sur les compétences de mathématique) chez des enfants âgés entre 2 et 12 ans ayant bénéficié d'une remédiation cognitive confirme que les programmes permettent un transfert rapproché ($p = .001$), mais que l'intervention ne permet pas un transfert éloigné ($p = .11$). Les auteurs suggèrent de cibler l'ensemble de la fonction exécutive lors de la remédiation cognitive. Afin de favoriser le transfert éloigné, une étude a émis l'hypothèse que l'inclusion de stratégies métacognitives pourrait favoriser ce transfert (Jones et al., 2020). Les chercheurs ont comparé trois groupes : un groupe entrainé avec un programme de remédiation cognitive seule (Cogmed), un groupe entrainé avec un programme de remédiation cognitive avec l'inclusion de stratégies métacognitives (MétaCogmed) et un groupe contrôle sans entrainement. Le programme

Cogmed vise l'amélioration de la mémoire de travail via un programme informatique. Ce programme comprend la répétition de tâches informatisées, des rétroactions et du renforcement. Il est d'une durée d'environ 15 heures s'échelonnant sur cinq semaines. La composante métacognitive inclut l'intégration de stratégies métacognitives lors des tâches informatiques. L'enfant doit répondre dans un cahier à des questions de base, comme « Quel est mon but? », «Quelles stratégies sont nécessaires pour accomplir la tâche et évaluer ma performance? », etc. L'étude a démontré que les groupes Cogmed et MétaCogmed s'améliorent significativement plus sur la mémoire de travail (transfert rapproché) lors des deux post tests (post intervention et trois mois après l'intervention) et sur le raisonnement mathématique (transfert éloigné) lors du post intervention seulement, comparativement au groupe contrôle. Les résultats étaient significativement plus élevés pour le groupe MétaCogmed. Ces conclusions suggèrent que la remédiation cognitive permet d'améliorer la fonction exécutive. Cependant, les études ne démontrent pas encore que la remédiation cognitive permet le transfert des nouveaux acquis dans la vie de tous les jours, tels que la résolution de problème. Par conséquent, il serait très pertinent pour le psychoéducateur de tenter de développer des nouvelles modalités d'intervention ciblant ce transfert puis d'en étudier leur effet.

D'autre part, le psychoéducateur peut cibler indirectement la fonction exécutive par le développement d'intervention ciblant les adultes significatifs de l'enfant. Le soutien à l'autonomie parental pourrait s'avérer une modalité efficace afin de développer la fonction exécutive, tel que mis en évidence par les études longitudinales, mais pourrait également favoriser le transfert éloigné de la fonction exécutive entrainée par la remédiation cognitive. Effectivement, le soutien à l'autonomie telle que défini par

Bernier inclut l'emploi de stratégies métacognitives, dont l'étayage. Il est un facteur prédictif important du développement de la fonction exécutive. De plus, le parent peut agir comme agent de transfert des stratégies ciblées par l'intervention dans les situations quotidiennes. Par exemple, il peut aider l'enfant à ralentir, réfléchir sur la tâche, jongler avec les informations importantes (mémoire de travail) lors de défis quotidiens. À notre connaissance, il n'existe pas d'intervention ciblant le soutien à l'autonomie parental dans le but de développer la fonction exécutive. Il serait intéressant de développer un programme d'intervention ciblant la remédiation cognitive avec l'ajout d'éléments de soutien à l'autonomie, incluant les stratégies métacognitives pour les enfants d'âges préscolaire ayant une inhibition comportementale élevée afin de prévenir l'anxiété à l'âge scolaire. Enfin, le psychoéducateur peut aider à cibler l'efficacité des fonctions exécutives par l'apprentissage de bonnes stratégies de régulation émotionnelle. Effectivement, l'efficacité des fonctions exécutives est influencée, entre autres, par l'intensité de l'émotion. Lorsque l'émotion est trop intense, les fonctions exécutives deviennent moins efficaces (Zelazo, Forston, Masten, et Carlson, 2018). L'apprentissage de stratégies de gestion des émotions permet donc l'amélioration de l'efficacité des fonctions exécutives.

3.4 Forces et limites de la thèse

Au-delà des forces et limites discutées précédemment pour chaque article, cette thèse a des forces et des limites globales à prendre en considération pour les recherches futures et l'application des résultats à la pratique clinique.

Il est d'abord important de mentionner les forces méthodologiques de cette thèse, qui permettent d'être confiants dans ces résultats. Premièrement, le devis longitudinal a permis de faire des analyses décalées croisées entre 5 et 7 ans entre deux types d'indicateurs de performance de la flexibilité cognitive: l'exactitude et le temps de réaction. Cela permet de mettre en lumière la séquence développementale de la flexibilité cognitive et du rôle médiateur de la mémoire de travail dans la relation entre le temps de réaction et l'exactitude. De plus, ce devis longitudinal a permis d'évaluer les rôles potentiellement modérateur ou médiateur de dimensions de la fonction exécutive dans la relation entre l'inhibition comportementale et l'anxiété. Deuxièmement, la taille de l'échantillon est importante (n = 425) et combinée avec l'utilisation de tâches cognitives de très bonnes qualités psychométriques, permet de généraliser à l'ensemble des enfants du Québec vivant dans un milieu urbain les résultats avec confiance. Cet aspect est à souligner, car l'utilisation de ce type de mesure demande beaucoup de ressources en temps et en argent aux équipes de recherche et aux familles ayant participé à l'étude. Troisièmement, les données manquantes sont fréquentes dans les études longitudinales et peuvent provoquer d'importantes erreurs d'estimation des paramètres. L'utilisation du *Robust maximum likelihood estimator* (MLR) a permis d'atténuer les erreurs d'estimation. Cette méthode réfère à l'estimateur du maximum de vraisemblance basée sur toutes les données disponibles sans l'utilisation d'imputation ou de la suppression des données.

L'une des principales limites est l'absence de mesure après 5 ans de l'inhibition cognitive. L'inhibition cognitive est une dimension parmi les trois principales de la fonction exécutive à l'âge préscolaire (Garon et al., 2008). C'est également une des fonctions principales du développement de la flexibilité cognitive selon certaines théories, dont l'inertie attentionnelle de Diamond (Diamond et al., 2005). De plus, une mesure longitudinale de l’inhibition cognitive nous aurait permis de tester l’hypothèse des processus cognitifs orientés vers les stimuli Fox et al., (2021). Dans une recherche future, il serait pertinent d’ajouter une telle mesure longitudinale adaptée à tous les âges.

Une seconde limite est l’absence de prise de mesure du temps de réaction pour le ROST, mesurant la mémoire de travail et pour le DCCS version marionnette, mesurant la flexibilité cognitive à 5, 6 et 7 ans. La première étude a confirmé l’importance du temps de réaction dans le développement de la flexibilité cognitive : le ralentissement prédit l’exactitude au temps suivant, mais pas de manière concurrente. Il serait intéressant d’évaluer si les résultats de la première étude s’appliquent également à d’autres tâches mesurant la flexibilité cognitive et la mémoire de travail.

Par ailleurs, les résultats de la première étude suggèrent que la médiane du temps de réaction des essais réussis et non réussis est un indicateur important du développement de la flexibilité cognitive pendant la transition préscolaire scolaire. Cependant, afin de maintenir une cohérence entre les variables des études dans ce domaine et ainsi pouvoir comparer les résultats entre celles-ci, la variable du temps de réaction n’a pas pu être utilisée dans la deuxième étude. Effectivement, la majorité des études examinant l’association entre le temps de réaction de l’anxiété inclut seulement le temps de réaction des essais réussis. Cette variable n’a pas pu être utilisée dans la deuxième étude étant donné le nombre restreint d’essais réussis chez les enfants de 6 ans (M : 15,58; é-t : 3,91). Dans une recherche future, il serait intéressant de mieux comprendre l’association développementale entre le temps de réaction et l’anxiété.

Une troisième limite, est l’absence de mesure d’observation validée de l’inhibition comportementale. Il est recommandé d’utiliser à la fois une procédure d’observation et le questionnaire car ainsi des facteurs tel que la désirabilité sociale sont contrôlés (Fox, Henderson, Rubin, Calkins, et Schmidt, 2001). Néanmoins, le questionnaire permet d'avoir la perception du parent sur comment son enfant réagit à la nouveauté.

En somme, les deux études de cette thèse contribuent à l'avancement de connaissances. La première étude a précisé la séquence développementale de la flexibilité cognitive et le rôle médiateur de la mémoire de travail dans ce développement. La seconde étude a permis de cerner le rôle modérateur de la flexibilité cognitive et de la mémoire de travail dans le développement de l'anxiété chez les enfants ayant une inhibition comportementale élevée. Ces résultats s'avèrent importants pour guider la recherche et l'intervention. Effectivement, le rôle de la fonction exécutive dans le développement de l'anxiété chez les enfants ayant un tempérament inhibé devrait être considéré dans le développement de programme de prévention. Cibler la flexibilité cognitive et la mémoire de travail peut s'avérer un facteur de protection pour le développement de l'anxiété, mais également pour d'autres problèmes d'adaptation. Certains programmes intégrés dans le programme préscolaire et scolaire comme *Tools of Mind* (Nesbitt et Farran, 2021) semblent prometteurs et permettraient de favoriser l'adaptation lors de la transition préscolaire-scolaire.

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