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Contrôle endogène chez les adolescents de 11 à 18 ans:
Développement normal et impacts d'un traumatisme cranio-encéphalique.

par

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Cette thèse porte sur la mesure des processus exécutifs liés au contrôle endogène à l'aide d'un paradigme de changement de tâche. Elle s'intéresse à la configuration des ressources de traitement en un schéma particulier approprié à l'accomplissement d'un type de tâche chez deux populations d'adolescents. Une première étude s'intéresse au développement de ce contrôle endogène chez des adolescents neurologiquement intacts âgés de 11-14 ans et de 15-18 ans. Une seconde étude porte sur l'impact d'un traumatisme cranio-encéphalique sur ce contrôle endogène auprès de trois adolescents.

Suite à la présentation d'un indice de tâche précédant la cible, les adolescents devaient répondre soit à la même tâche qu'à l'essai précédent (maintien) ou à une tâche différente (alternance), présentées dans un ordre aléatoire. Pour les deux études, les expériences 1 varient l'intervalle indice-cible, alors que l'intervalle de temps entre la réponse à un essai précédent et la présentation de l'indice est constant. Les expériences 2 varient l'intervalle réponse-indice, alors que l'intervalle indice-cible demeure constant.

Les résultats obtenus à l'expérience 1 de la première étude montrent une diminution des coûts de changement de tâche (temps de réaction et/ou taux d'erreur plus grand lors des essais " alternance " que " maintien ") avec l'augmentation de l'intervalle incide-cible. De plus, les 11-14 ans montrent de plus grands coûts de changement de tâche que les 15-18 ans. Le groupe des 11-14 ans montre aussi de plus longs temps de réaction que les 15-18 ans, avec une réduction graduelle de cette différence avec l'augmentation des intervalles indice-cible. À l'expérience 2, la variation des intervalles réponse-indice n'a pas d'impact systématique sur les coûts de changement de tâche. On retrouve toutefois comme à l'expérience 1 de plus grands coûts de changement de tâche chez les 11-14 ans que chez les 15-18 ans. Les résultats sont discutés en relation avec une maturation des mécanismes impliqués dans le contrôle endogène durant l'adolescence.

Les résultats obtenus auprès des sujets contrôles de la seconde étude indiquent des coûts de changement de tâche (temps de réaction et/ou taux d'erreur plus grand lors des essais "alternance" que "maintien") qui s'amenuisent avec l'augmentation de l'intervalle indice-cible, mais qui ne sont pas affectés par la variation des intervalles réponse-indice. Les trois patients ont des anomalies majeures comparées aux performances de leur groupe contrôle respectif. Toutefois, ces anomalies sont qualitativement différentes. Un de ces patient montre un coût de changement de tâche significativement supérieur à son groupe témoin. Un autre patient ne montre aucun coût de changement de tâche. Enfin, le coût de changement de tâche d'un troisième patient n'est pas influencé par les variations des intervalles indice-cible. Ces observations suggèrent des possibilités d'atteintes variées du contrôle endogène suite à un TCE, de même qu'elles mettent en évidence l'existence de différents mécanismes de contrôle endogène dans la cognition d'adolescents neurologiquement intacts.

Mots Clés : Fonctions exécutives; Contrôle endogène; Développement; Traumatisme cranio-encéphalique; Paradigme de changement de tâche.

SUMMARY

This thesis is concerned with the measurment of the executive processes associated with endogenous control with the use of a task-switching paradigm. It is interested in the configuration of processing resources into a behavioral schema appropriate for the performance of a particular task in two populations of adolescents. A first study is concerned with the development of endogenous control in groups of neurologically intact adolescents aged 11-14 and 15-18 years old. A second study examines the impact of a traumatic brain injury on this endogenous control in three adolescents.

Following the presentation of a task-cue preceding the target, the adolescents had to respond according either to the same task as that on the previous trial (hold) or to a different task (switch), which were presented in a random order. In both studies, the experiments 1 involved variations of the cue-target interval, whereas the time interval between the response to the previous trial and the cue remains constant. The experiments 2 vary the response-cue interval, whereas the cue-target interval remains constant.

The results from experiment 1 of the first study show a reduction of task-switch costs (greater reaction times and/or error rates on "switch" than on "hold" trials) with an increase of the cue-target interval. Moreover, the 11-14 year-old participants show greater task-switch costs than the 15-18 year-old group. The 11-14 year-old group also shows longer reaction times than the 15-18 year-olds, with a gradual reduction of this difference with an increase of the cue-target interval. In experiment 2, the variation of the response-cue interval had no systematic impact on task-switch costs. However, as in experiment 1, task-switch costs are greater in the 11-14 than in the 15-18 year-olds. These results are discussed in relation with the maturation of the mechanisms involved in endogenous control during adolescence.

The results from the control subjects of the second study indicate task-switch costs (greater reaction times and/or error rates on "switch" than on "hold" trials) that diminish with an increase of the cue-target interval, but which are unaffected by a variation of the response-cue interval. The three patients examined show major anomalies compared with the performances of their respective control group. However, these anomalies are qualitatively different across patients. One of these patients shows a task-switch cost that is significantly greater than that of his control group. Another patient shows no task-switch costs. Finally, the task-switch costs of a third patient are unaffected by variations of the cue-target interval. These observations suggest the possibility of variable impairments of endogenous control following traumatic brain injury and provide evidence for different mechanisms of endogenous control in the cognition of neurologically intact adolescents.

Key words: Executive functions; Endogenous control; Development; Traumatic brain injury; Task-switching paradigm.

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INTRODUCTION GÉNÉRALE

Le développement des mécanismes permettant l'expression des fonctions exécutives représente une étape essentielle pour le déploiement optimal de l'ensemble du comportement. Au cours des dernières années, l'intérêt des chercheurs pour l'attention et les fonctions exécutives a suscité une multitude de travaux sur ces thèmes, tant chez l'individu neurologiquement intact que chez le sujet cérébrolésé. Malgré cela, plusieurs limites se posent toujours dans la compréhension des mécanismes impliqués par ces fonctions, particulièrement lors de leur atteinte. En effet, leur complexité et le fait qu'ils interagissent avec l'ensemble des autres fonctions cognitives et perceptivo-motrices rendent souvent difficile une définition claire des éléments en jeu. Cette difficulté nuit à la mesure des mécanismes à l'étude de même qu'à l'interprétation des résultats obtenus aux tâches sensées les mesurer. D'ailleurs, un grand nombre des instruments de mesure utilisés pour évaluer l'attention et les fonctions exécutives nécessite la participation d'une multitude de processus, tous susceptibles d'affecter les performances observées, rendant ainsi difficile l'interprétation d'une atteinte à ces tâches. De plus, les instruments utilisés sont le plus souvent issus de travaux auprès de sujets adultes et peu d'études développementales les ont validés auprès d'une population plus jeune. Ces différentes limites illustrent les défis posés par l'étude de l'attention et des fonctions exécutives lors du développement.

Cette thèse porte sur le contrôle endogène, soit un sous-ensemble de mécanismes liés à la composante intentionnelle du contrôle lors de l'exécution d'une tâche ("task-control"), qui est attribué au système de supervision attentionnelle (SSA ; Norman et Shallice, 1986), ou centrale exécutive (Rogers et Monsell, 1995). Les participants aux études sont des adolescents âgés entre 11 et 18 ans qui appartiennent à deux types de population. Un premier type est composé de jeunes neurologiquement intacts, alors que le second type est constitué de participants ayant subi un traumatisme cranio-encéphalique. Un paradigme de changement de tâches est utilisé afin d'étudier le fonctionnement des mécanismes de contrôle endogène (Meiran, 1996; Rogers et Monsell, 1995). Ce paradigme permet d'évaluer les processus de contrôle impliqués dans la reconfiguration des ressources de traitement en un nouveau schème comportemental lors d'une modification de la tâche à accomplir à travers des essais consécutifs. L'intégrité du contrôle endogène sous-tend l'organisation flexible du comportement et est donc essentielle à l'adaptation aux activités complexes et changeantes de la vie de tous les jours. Pour ces différentes raisons, un dysfonctionnement du contrôle endogène peut occasionner un handicap fonctionnel majeur.

L'Introduction de la thèse présente une brève revue des éléments théoriques et empiriques les plus importants pour le travail proposé. Elle débute par la définition du cadre théorique des fonctions exécutives. Une présentation plus approfondie du concept de contrôle endogène et de son opérationalisation est ensuite proposée. Elle aborde par la suite les définitions et l'état de la recherche concernant les fonctions exécutives et leur développement chez les adolescents neurologiquement intacts, puis auprès d'individus ayant subi un traumatisme cranio-encéphalique. Elle discute ensuite des études portant sur l'alternance entre différentes tâches auprès de sujets neurologiquement intacts. Elle termine par un aperçu des principaux résultats retrouvés chez les populations à l'étude et par une présentation des hypothèses de recherche. Deux articles forment ensuite la partie empirique de la thèse. L'Article 1 porte sur le développement du contrôle endogène chez les adolescents neurologiquement sains âgés entre 11 et 18 ans. L'article 2 vise l'étude des altérations de certains mécanismes du contrôle endogène chez trois adolescents ayant subi un traumatisme cranio-encéphalique modéré. Les deux articles permettent d'isoler certains des mécanismes spécifiques mis en jeu dans le processus de contrôle endogène. La Discussion Générale de la thèse résume les principaux résultats obtenus de même que de leurs implications pour la compréhension du contrôle endogène chez les deux populations à l'étude.

LES FONCTIONS EXÉCUTIVES

Définition

La plupart des auteurs dans le domaine s'accordent pour définir les fonctions exécutives comme un ensemble d'habiletés interreliées qui sont nécessaires au maintien approprié d'un comportement de résolution de problèmes lors de l'accomplissement d'activités à but dirigé (Lezak, 1983 ; Stuss et Benson, 1986). Shallice (1988) précise que ces fonctions ne servent pas à l'accomplissement d'actions routinières, mais jouent plutôt un rôle fondamental lors de situations nouvelles et non familières (i.e. pour lesquelles aucune routine ou schème n'existe déjà).

Modèle théorique des fonctions exécutives

Norman et Shallice (1986) proposent un modèle théorique visant à expliquer l'articulation et l'enchaînement adéquat des schèmes (routines) entre eux. De type hiérarchique, ce modèle du système de supervision attentionnelle (SSA) comporte deux niveaux de contrôle du comportement. Le premier niveau, appelé répartiteur de schèmes ("contention scheduling"), contrôle l'exécution de schèmes comportementaux de façon semi-automatique à travers un système de résolution de conflits, alors que différents schèmes sont déclenchés par les stimuli disponibles dans l'environnement. Ce répartiteur de schèmes gère la compétition entre les schèmes et permet l'accomplissement de l'un d'entre eux. À ce niveau, les schèmes incompatibles s'inhibent mutuellement alors que les schèmes compatibles s'activent mutuellement. En raison de son caractère semi-automatique, ce niveau de traitement est conçu comme agissant rapidement mais de façon rigide ou stéréotypée. Si aucun schème n'a pu s'actualiser à partir de ce premier niveau de contrôle ou dans le cas de situations particulières, le SSA prendra la relève et adoptera le schème requis. Ce second niveau offre un contrôle flexible mais plus lent que celui offert par le répartiteur de schèmes. Le système de supervision doit sélectionner une combinaison particulière de routines lorsqu'un nouveau type de réponse est exigé, en maintenant et/ou en alternant entre les différents schèmes afin de produire un comportement stratégique. Ce système est sollicité dans les situations suivantes: a) planification et prise de décision, b) autocorrection des activités en cours, c) exigence de nouvelles réponses, pas encore automatisées ou qui contiennent de nouvelles séquences d'actions, d) situations jugées dangereuses ou techniquement difficiles, et e) situations requérant l'arrêt d'activités automatisées qui sont déjà en cours.

Peu de paradigmes permettent l'analyse efficace et précise du SSA. En effet, une forte majorité des recherches qui se sont penchées sur le fonctionnement de l'attention et des fonctions exécutives se sont intéressées à l'étude des performances obtenues lors de l'accomplissement continu d'une ou de plusieurs tâches dans lesquelles différents facteurs, tel le niveau de difficulté ou encore le mode de présentation, sont variés. Par ailleurs, les instruments de mesure cliniques, fort utiles dans le dépistage des atteintes des fonctions exécutives, sont limitées par leur caractère multi-modal.

En ce qui concerne les paradigmes issus des approches du traitement de l'information, quelques études évaluant les mécanismes associés au contrôle endogène offrent des avenues prometteuses pour l'étude du SSA.

LE CONTRÔLE ENDOGÈNE

Paradigme de changement de tâches

Jersild (1927) fut le premier à proposer l'utilisation d'un paradigme de changement de tâches afin de quantifier la durée d'un processus de contrôle chargé de la reconfiguration du schème comportemental avant le traitement du prochain stimulus. La mesure de ce processus de contrôle s'effectue par la soustraction des temps de réaction obtenus en condition de base, lors de l'accomplissement répétitif d'une même tâche ("AAAA" ou "BBBB"; i.e. blocs d'essais où la tâche à effectuer est toujours la même, soit la tâche A, soit la tâche B), des temps de réaction obtenus en condition d'alternance entre deux tâches ("ABABAB"). Ce coût de changement de tâches serait, selon Jersild, une mesure du processus de contrôle qui s'opère avant de traiter le prochain stimulus, soit un mécanisme sous la responsabilité des fonctions exécutives qui anticipe le traitement qui sera à effectuer.

Allport et al. (1994) ont critiqué cette interprétation. Ils expliquent que le coût de changement de tâches observé correspondrait plutôt à une inertie du schème comportemental ("Task-Set Inertia"), soit le reflet de la configuration résiduelle du schème précédemment adopté. Plus précisément, ce coût serait causé par une interférence proactive, ralentissant l'exécution d'une nouvelle tâche, plutôt que par un processus endogène de reconfiguration comme le proposait Jersild.

Allport et al. ont mené une série d'expériences visant à confirmer cette explication du coût de changement de tâches. La manipulation critique consiste à introduire des intervalles temporels variables entre la réponse à un essai et la présentation du stimulus pour l'essai suivant, et ce, dans le contexte d'un paradigme du type "ABAB" vs "AAAA" ou "BBBB". Selon l'hypothèse de l'inertie du schème comportemental, l'augmentation des intervalles inter-essais ne devrait pas avoir d'impact sur le coût de changement de tâches, qui devrait néanmoins diminuer graduellement après plusieurs essais consécutifs d'une même tâche ("AAAA" ou "BBBB"). Par contre, si l'on retrouvait une élimination du coût de changement de tâches suite à un long intervalle inter-essais, il s'agirait alors d'un phénomène associé au SSA, ce dernier effectuant une reconfiguration du schème comportemental avant le début du nouvel essai. Les résultats obtenus démontrent un maintien du coût de changement de tâches, même pour de très longs intervalles inter-essais ce qui, selon Allport et al., confirme l'hypothèse de l'inertie du schème comportemental.

Selon Rogers et Monsell (1995), la méthodologie impliquant une séparation des conditions en blocs d'essais distincts utilisée par Allport et al. nuirait à la mesure des mécanismes en jeu. En effet, les blocs d'essais de même tâche et ceux comprenant deux tâches différentes ("ABAB" vs "AAAA" ou "BBBB") ne représentent pas des conditions comparables au niveau de la charge mentale requise. Ainsi la condition expérimentale ("ABAB") nécessite, en plus d'une reconfiguration du schème comportemental à chaque essai, le maintien de deux schèmes comportementaux actifs, ce qui n'est pas le cas pour la condition sans changement de tâches ("AAAA" ou "BBBB"). De plus, les demandes inhérentes à ces deux conditions diffèrent également au niveau de l'effort, de l'éveil, des critères de réponse, et des stratégies d'exécution de chaque tâche.

Dans le but de mieux isoler les variables à l'étude, Rogers et Monsell proposent le paradigme "AABBAABB" où deux essais d'une même tâche sont ensuite suivis de deux essais impliquant une autre tâche. Faisant usage de ce nouveau paradigme, ces auteurs s'intéressent à l'activation exogène, qui se produit lorsque les stimuli eux-mêmes induisent l'émission de comportements qui leur sont associés, ceux-ci pouvant être en conflit avec l'intention du sujet. L'indiçage exogène est produit par l'introduction d'un stimulus ou d'un attribut non pertinent pour la tâche actuelle, mais qui l'était à l'essai précédent. Par exemple, l'indiçage exogène peut se manifester lorsque les sujets doivent indiquer si la lettre présentée à un essai est une consonne ou une voyelle puis, à l'essai suivant, si le chiffre est pair ou impair, comme dans la séquence: G8, L4, où la cible est le stimulus souligné. La lettre "L" au second essai s'avère non pertinente puisqu'elle n'est pas la cible. Celle-ci est néanmoins liée à la lettre "G" qui était la cible lors de la tâche précédente, ce qui est susceptible d'affecter le coût de changement de tâches. Rogers et Monsell ont examiné la contribution d'un tel indiçage exogène au coût de changement de tâches en comparant les performances lors de séquences d'essais pouvant produire un indiçage exogène (e.g. : G8, L4) à celles observées dans une condition neutre ne pouvant produire aucun indiçage de ce type (e.g. S2; ☐ 7; où ☐indique un espace vide).

Dans leur étude, Rogers et Monsell ont également mesuré la contribution du "crosstalk" (croisement des clés de réponse) au coût de changement de tâches. Le "crosstalk" peut se manifester dans une situation où les mêmes clés de réponse servent à la production de catégories de réponses distinctes pour les deux tâches à effectuer. Par exemple, si une des tâches consiste en une catégorisation de lettres consonne/voyelle et l'autre demande une catégorisation de chiffres pair/impair, l'une de deux clés de réponse peut être assignée aux réponses voyelle/pair et l'autre aux réponses consonne/impair. Dans de telles conditions, un essai constitué des stimuli K2 est incongruent sur le plan des réponses associées à la lettre (cible) et au chiffre alors qu'un essai impliquant les stimuli A8 serait considéré comme congruent. La condition neutre décrite plus haut sert de nouveau à Rogers et

Monsell comme niveau de base pour l'évaluation de la contribution du "crosstalk" au coût de changement de tâches.

Les résultats de Rogers et Monsell démontrent tout d'abord des coûts de changement de tâches significatifs qui ne sont pas attribuables à des artéfacts telles des différences de charge mentale entre les conditions, contrairement aux études précédentes du coût de changement de tâches. Ils observent également des effets significatifs de l'indiçage exogène et du "crosstalk" tant au niveau des temps de réaction que des coûts de changement de tâches. Cependant, les résultats obtenus dans leur condition neutre mettent également en évidence des coûts de changement de tâches qui ne peuvent être attribués ni à l'indiçage exogène, ni au "crosstalk".

Rogers et Monsell font un parallèle entre les effets d'indiçage exogène et de "crosstalk" qu'ils ont observés et l'altération du contrôle endogène chez les patients frontaux. Ainsi, les effets de "crosstalk" et de l'indiçage exogène sur les comportements des participants neurologiquement intacts suggèrent la mise en application de schèmes comportementaux qui sont induits par les stimuli présentés ou les modalités de réponse disponibles et qui ne correspondent pas à la volonté des sujets. Ceci rappelle les comportements de persévération et d'utilisation de même que les erreurs de capture observés chez les patients avec atteinte frontale (Rogers et Monsell, 1995). Ceux-ci suggèrent une dominance du contrôle exogène exercé par stimuli environnementaux, mettant ainsi en évidence une altération de la fonction du SSA. Donc, les conditions expérimentales étudiées par Rogers et Monsell permettent de démontrer que même les sujets normaux peuvent manifester une difficulté de contrôle endogène en raison de la force des stimuli exogènes.

Rogers et Monsell ont également étudié l'effet de la variation des intervalles inter-essais, comme l'avaient fait Allport et al. précédemment. Leurs résultats indiquent une réduction significative du coût de changement de tâches avec l'augmentation des intervalles. Pendant les premières 600 msec de l'intervalle inter-essais, le coût de changement de tâches perd le tiers de sa force, pour ensuite se stabiliser et demeurer constant à travers les intervalles supérieurs à 600 msec. Ces auteurs concluent donc que la réduction du coût de changement de tâches en fonction de l'augmentation de l'intervalle inter-essais serait associée à un processus endogène de reconfiguration du schème comportemental qui se produit dans les 600 premières msec suite à l'émission d'une réponse. Bien que la reconfiguration serait initiée de façon endogène, Rogers et Monsell proposent que la présence de la cible est nécessaire afin de déclencher un mécanisme exogène complétant la reconfiguration. Il y aurait donc une action combinée et séquentielle des mécanismes de contrôle endogène et exogène. Alors que le contrôle endogène expliquerait la diminution des coûts de changement de tâches avec l'augmentation des intervalles inter-essais, le contrôle exogène expliquerait le coût résiduel stable observé avec des intervalles supérieurs à 600 msec. Il est à noter que les résultats rapportés par Rogers et Monsell ressemblent fortement à ceux obtenus précédemment par Allport et al., quoique ces derniers aient particulièrement insisté sur l'observation de coûts résiduels aux longs intervalles inter-essais en faisant abstraction de la réduction des coûts de changement de tâches à travers les intervalles plus courts.

Ce sont toutefois les travaux de Meiran (1996) qui permettent d'identifier le plus clairement les mécanismes du SSA impliqués dans le changement de tâches. Selon cet auteur, dans les conditions expérimentales de changement de tâches, le comportement est conjointement déterminé par les processus de contrôle qui effectuent la reconfiguration du schème de comportemental, et les processus de bas niveau qui exécutent la tâche demandée. Il établit deux critères dont l'atteinte permettrait la démonstration des effets du processus exécutif de contrôle endogène. Premièrement, le coût de changement de tâches observé ne doit être attribuable qu'au changement de tâches et non à des artéfacts telle la charge mentale (voir plus haut). Deuxièmement, il propose un critère de proactivité selon lequel il est nécessaire de démontrer que la reconfiguration du schème comportemental responsable du coût de changement de tâches est effectuée à l'avance, en anticipation de la tâche à effectuer sur la prochaine cible plutôt que de constituer un ajustement rétroactif suite à la présentation de la cible.

À la lumière de ces critères, Meiran présente une critique élaborée des paradigmes expérimentaux utilisés précédemment par Rogers et Monsell et par Allport et al.. Il souligne en particulier la difficulté que ces paradigmes présentent à distinguer la reconfiguration proactive du schème comportemental des effets pouvant être liés à l'ajustement rétroactif ou à l'inertie du schème comportemental (i.e. interférence proactive).

Afin de résoudre ces difficultés et de rencontrer les deux critères permettant d'identifier le coût de changement de tâches comme fonction du contrôle endogène (i.e. un processus exécutif), Meiran propose un nouveau paradigme incluant 1) deux tâches distribuées dans un ordre aléatoire à l'intérieur d'un même bloc d'essais et 2) la présentation d'un indice prévenant les participants de la tâche à accomplir avant l'apparition de la cible. Cette formule expérimentale a permis à Meiran de mesurer de façon indépendante les effets de deux composantes distinctes de l'intervalle inter-essais étudié précédemment par Allport et al. et par Rogers et Monsell, soit l'intervalle de temps séparant la production de la réponse à un essai et la présentation de l'indice à l'essai suivant (intervalle réponse-indice; IRI) et l'intervalle entre la présentation de l'indice de tâche et la présentation de la cible (intervalle indice-cible; IIC).

L'utilisation d'un indice de tâche conjointement à la manipulation des intervalles IRI et IIC a permis à Meiran de clairement démontrer la contribution d'un processus endogène de reconfiguration du schème comportemental dans le coût de changement de tâches. Ainsi, ses résultats démontrent une réduction substantielle et graduelle du coût de changement de tâches avec une augmentation de l'intervalle IIC (alors que l'intervalle inter-essais total, i.e. entre la production de la réponse à un essai et la présentation de la cible à l'essai suivant, demeure fixe). Cette observation indique que le coût de changement de tâches ne peut être attribué exclusivement à des effets d'ajustement rétroactif ou d'interférence proactive, qui prédisent tous deux un coût invariant dans des conditions où l'intervalle inter-essais total demeure fixe. L'effet indépendant de l'intervalle IIC indique plutôt le rôle important d'un processus de reconfiguration proactive du schème comportemental dans la modulation du coût de changement de tâches. Plus spécifiquement, l'effet de l'IIC suggère que les participants initient de façon endogène la reconfiguration de leur schème comportemental dès la présentation de l'indice de tâche lors des essais où la tâche à effectuer est différente de celle à l'essai précédent. Plus l'IIC est élevé, plus les participants sont avancés dans ce processus de reconfiguration au moment où la cible est présentée, entraînant par conséquent une réduction du coût de changement de tâches.

Dans le but de tester la généralité de ses observations, Meiran a également étudié les effets indépendants des intervalles IRI et IIC avec différentes combinaisons de paires de tâches (localisation/identification ou couleur/ identification). Les résultats obtenus ont démontré la généralité du phénomène observé, qui semble concerner effectivement un processus exécutif de reconfiguration du schème comportemental plutôt que d'être spécifique à la réalisation d'une tâche ou d'une paire de tâches particulières. Cette absence d'effet lié à la nature de la tâche à effectuer a également permis de conclure que la reconfiguration du schème comportemental prend place à un niveau fonctionnellement distinct des étapes de traitement perceptif et moteur qui sont requises dans la réalisation d'une tâche quelconque.

DÉVELOPPEMENT DES FONCTIONS EXÉCUTIVES

Études neuropsychologiques

L'étude du développement des fonctions exécutives implique principalement la mesure de comportements à buts dirigés, incluant la planification, la recherche visuelle organisée et le contrôle des impulsions. Les études portant sur ce thème reposent en majeure partie sur l'utilisation de tâches neuropsychologiques conçues à l'origine pour évaluer l'intégrité des aires frontales chez l'adulte et qui ont été adaptées à l'enfant (Anderson, Anderson et Lajoie, 1996; Becker, Isaac, et Hynd, 1987; Chelune et Baer, 1986; Passler, Isaac et Hynd, 1985; Welsh, Pennington et Groisser, 1991). D'autres études visent essentiellement à recueillir des normes développementales à partir d'outils cliniques pour adultes (Chelune et Baer, 1986; Kirk et Kelly, 1986; Waber et Holmes, 1985).

Les résultats de ces études développementales décrivent une amélioration séquentielle des performances lors de tâches dites exécutives (Passler, Isaak et Hynd, 1985; Welsh, Pennington et Groisser, 1991). On retient comme principales étapes de développement des fonctions exécutives, les âges de 6 ans, 10 ans et 12 ans et plus, alors qu'émergeraient graduellement des habiletés s'apparentant au fonctionnement adulte (Becker, Isaac et Hynd, 1987 ; Chelune et Baer, 1986; Passler, Isaac et Hynd , 1985; Welsh, Pennington et Groisser, 1991). À cet égard, certains auteurs ont proposé que dès l'âge de 12 ans, les fonctions exécutives auraient atteint leur niveau de fonctionnement adulte (Appelof et Augustine, 1986; Chelune et Baer, 1986; Kirk et Kelly, 1986). D'autres études, par contre, soulèvent la possibilité que le développement des fonctions exécutives puissent se poursuivre au cours de l'adolescence.

Par exemple, les résultats de Welsh, Pennington et Groisser (1991) démontrent que les tâches de planification simple (Tour d'Hanoi) et de recherche visuelle sont accomplies adéquatement par des enfants de 6 ans. Par contre, ce n'est qu'à l'âge de dix ans que semblent émerger les capacités d'évaluation d'hypothèse et de contrôle des impulsions, telles que mesurées par le test du Wisconsin (WCST). Enfin, les jeunes de 12 ans montrent des performances supérieures à celles de ceux de 10 ans. Toutefois, leur performance n'atteignait pas encore un niveau de fonctionnement adulte dans les tâches de fluidité verbale et de séquences motrices de même que dans les tâches évaluant les habiletés de planification complexe. Ces derniers résultats suggèrent donc la possibilité d'une étape développementale survenant au cours de l'adolescence, soit après l'âge de 12 ans.

On ne répertorie pour l'instant aucune étude développementale portant spécifiquement sur la capacité de contrôle endogène. Toutefois, une étude concernant l'habileté à réorienter l'attention auditive chez les 8-19 ans semble pertinente (Pearson et Lane, 1991). Ainsi, Pearson et Lane ont démontré une amélioration quantitative des performances avec l'âge dans la tâche d'écoute dichotique. Ces résultats mettent notamment en évidence la présence de gains développementaux après l'âge de 12 ans au niveau de processus qui semblent apparentés aux fonctions exécutives. Ceci appuie l'intérêt de l'étude du développement des fonctions exécutives pendant l'adolescence.

Développement cérébral et fonctions exécutives

Les résultats de plusieurs études appuient la notion selon laquelle le développement des fonctions exécutives serait lié à celui des aires antérieures du cerveau, et plus particulièrement des aires préfrontales. En effet, les étapes de développement mises en évidence par les résultats aux tâches neuropsychologiques vont de pair avec les bonds développementaux constatés au niveau des lobes frontaux (Bell et Fox, 1992; Levin, Culhane, Hartmann, Evankovich, Mattson, Harward, Ringholz, Ewing-Cobbs et Fletcher, 1991; Thatcher, 1991-92; Welsh et Pennington, 1988). Sur le plan neurophysiologique, Epstein (1974) rapporte trois points culminants du développement cérébral survenant entre les âges de 6 à 8 ans, 10 à 12 ans et 14 à 16 ans. De plus, les résultats des études portant sur la myélinisation du cerveau, qui peuvent servir d'indicateur du développement du système nerveux, montrent une augmentation du processus de myélinisation au-delà de l'âge de 15 ans (Fleschsig, 1920, cité dans Nowakowski, 1987).

TRAUMATISME CRANIO-ENCÉPHALIQUE

Définition du traumatisme cranio-encéphalique

Le traumatisme cranio-encéphalique (TCE) se définit comme une atteinte cérébrale ou tronculaire causée par différents mécanismes lésionnels, soit de contusion, de lacération, coup-contre-coup, ou de fracture du crâne avec ou sans enfoncement. Le TCE peut être provoqué par des accidents à basse ou haute vitesse, mais c'est particulièrement dans cette dernière condition que des atteintes diffuses surgissent. Le TCE entraîne un changement soudain de l'état de conscience dont la sévérité est variable d'un individu à l'autre. Dans une forte proportion des cas, le traumatisme entraîne des complications neurologiques et par conséquent, l'apparition de déficits cognitifs et physiques (Beaulne, 1991; Charron, 1992). La gravité et la persistance des déficits cognitifs sont associées à la sévérité du traumatisme, qui est habituellement évaluée par la profondeur et la durée du coma, ainsi que par la durée de l'amnésie post-traumatique (test d'amnésie et d'orientation de Gavelston:TAOG; Brink, Garrett, Hale, Woo-Sam et Nickel, 1970; Craft, Shaw et Cartlidge, 1972; Dalby et Obrzut, 1991; Jennet et Bond, 1975).

Traumatisme cranio-encéphalique et déficits exécutifs

Bien que le TCE ait la particularité d'entraîner fréquemment des dommages diffus, les lobes frontaux sont presque invariablement atteints (Levin, Goldstein, Williams, Eisenberg, 1987). En effet, les techniques de résonance magnétique et de potentiels évoqués démontrent clairement que les lobes frontaux sont les régions les plus souvent touchées lors d'un TCE (Levin et al, 1987).

En conséquence de l'atteinte cérébrale causée par le TCE, des altérations comportementales sévères sont parfois observées. Celles-ci peuvent se résorber plusieurs semaines ou mois après le traumatisme, quoique des déficits au niveau des comportements d'autorégulation puissent persister plusieurs années après le traumatisme. Il peut alors s'agir d'un syndrome post-traumatique, où les patients atteints se plaignent d'altérations comportementales malgré l'absence de signes neurologiques persistants (Teuber, 1969).

Le tableau clinique de type "frontal" est fréquemment présent chez le sujet TCE (Goldberg, Bilder, Hugues et al, 1989; Lezak, 1983; Luria, 1980; Van Zomeran, Brouwer et Deelman, 1984). Luria (1973) caractérise ce tableau clinique comme le reflet d'un déficit affectant la formulation de l'intention et l'orchestration des comportements nécessaires pour l'atteinte d'un but. Ceci se manifeste sur le plan comportemental par de la désinhibition, de la persévération, des difficultés à initier des activités appropriées, à maintenir attention et effort à travers le temps, à reconnaître et à utiliser l'information rétroactive, ou encore à moduler des activités indépendantes (Benton, 1991; Evankovitch et al, 1990; Mateer et Williams, 1991). La présence fréquente d'une atteinte frontale chez les patients TCE est congruente avec le fait que les déficits comportementaux qu'ils présentent sont similaires à ce qui est observé lors de lésions frontales focales (Perret, 1974).

L'apparition de déficits exécutifs et attentionnels suite à un TCE est documentée par plusieurs auteurs (Gronwall et Sampson, 1974; Gronwall et Wrightson, 1974; MacFlynn, Montgomery, Fenton et Rutherford, 1984; Conkey, 1938; Dencker et Lofving, 1958; Goldstein, 1952; Meyer, 1904; Ruesch, 1944, tiré de Van Zomeran, 1981; Van Zomeran et Deelman, 1976). Ces déficits sont cependant définis différemment selon les auteurs, qui y réfèrent soit comme: a) une perte de la capacité à appréhender et à manipuler plusieurs aspects des stimuli et des difficultés à se concentrer ou à focaliser l'attention (Goodglass et Kaplan, 1979); b) des troubles de concentration décrits comme de l'impersistance (Ben-Yishay, Rattok et Diller, 1979; cité dans Goldstein et Goldstein, 1990); c) une indifférence apparente combinée paradoxalement à de la distractibilité et à un déficit dans l'initiation et le maintien d'une réponse (Filskov, Grimm et Lewis, 1981). Bien que ces descriptions reflètent le niveau de compréhension actuel de l'atteinte cognitive chez le TCE, leur hétérogénéité suggère également une absence de consensus sur sa nature exacte.

Il est à souligner que l'étude des fonctions exécutives auprès de la population TCE infantile demeure encore peu étayée. D'abord, à l'instar des études développementales, les instruments de mesure utilisés sont souvent des épreuves qui ont été développées pour l'étude d'une population adulte (Cooley et Morris, 1990). De plus, on remarque, tant pour les recherches chez les TCE-enfants que chez les TCE-adultes, que le type de fonction exécutive à l'étude est rarement défini de façon systématique. Enfin, l'étude des fonctions exécutives est souvent confondue avec l'étude des fonctions attentionnelles, étant donné probablement les difficultés à définir les fonctions exécutives de façon systématique. Cette problématique entraîne par le fait même l'utilisation de mesures ne reflétant pas nécessairement les mécanismes sensés être étudiés. En tenant compte de ces limites, nous présentons ici les études faisant état des performances auprès des TCC.

L'attention focalisée se définit comme la capacité à sélectionner une stimulation ou un comportement pertinents à la réalisation d'une tâche donnée et à inhiber ceux en compétition (Posner, 1975). Peu d'auteurs notent un problème d'attention focalisée chez le sujet TCE. Plusieurs notent cependant que le temps de passation des épreuves d'évaluation est significativement augmenté chez le TCE comparativement au sujet normal (Chadwick, Rutter, Shaffer et Shrout. 1981: TCE-enfants et TCE-adultes; Gentilini, Nichelle et Schoenhuber, 1989; Gronwall et Sampson, 1974 ; Stuss, Hugenholtz, 1985 et Van Zomeran et al. 1984).

Bien que les épreuves formelles d'évaluation n'aient que rarement permis de mettre en évidence une atteinte de l'attention focalisée chez les TCE, il n'en est pas de même des observations cliniques. Ainsi, les enfants TCE se laissent fréquemment interrompre par de l'interférence provenant de réflexions internes ou simplement par les bruits environnants qu'ils n'arrivent pas à inhiber. Ces difficultés donnent lieu à de fréquentes erreurs dans le contexte d'épreuves diverses ou encore, tel que noté plus haut, à une augmentation du temps de passation de la tâche.

Une distribution de l'attention à travers deux ou plusieurs sources d'information correspond au concept d'attention divisée. Les auteurs s'entendent pour rapporter une détérioration dramatique de l'attention divisée chez les patients TCE. Il s'agirait en effet du principal déficit attentionnel chez le TCE-adulte (Gray, 1990; Van Zomeran et Brouwer, 1990). Par exemple, Gronwall et Sampson (1974) rapportent, lors d'une étude faisant usage du PASAT, une détérioration marquée des performances lorsque les opérations concurrentes d'écoute, de calcul et de production d'une réponse verbale doivent être effectuées à un rythme de un chiffre à la seconde plutôt qu'à un rythme d'un chiffre aux trois secondes. De façon similaire, Gentilini et al. (1989) rapportent une augmentation significative des temps de réaction en tâche double chez des sujets TCE évalués à un mois post-trauma lorsque comparés à des sujets contrôles. Ainsi, les sujets TCE présentent des performances comparables à celles des sujets normaux lorsqu'une tâche de décompte numérique (compter à rebours) ou une tâche d'annulation de chiffres sont accomplies individuellement. Par contre, lorsque ces tâches sont effectuées simultanément, une plus forte augmentation des temps de réaction est observée dans le groupe TCE comparativement au groupe contrôle.

Par ailleurs, les TCE montrent généralement une augmentation dramatique du temps de réponse et du nombre d'erreurs en fonction du nombre d'alternatives de réponse dans les épreuves de temps de réaction au choix (Gronwall et Sampson, 1974; Miller, 1970; Van Zomeran et Deelman, 1976). Il apparaît également que la sévérité du déficit observé est proportionnelle à la durée du coma. Ces observations impliquent un ralentissement de la prise de décision et du traitement de l'information chez le patient TCE. Celles-ci pourraient également s'expliquer par une difficulté à configurer différentes réponses dans une tâche offrant plusieurs alternatives de réponses.

Problématique particulière aux lésions cérébrales chez les jeunes.

Russell (1948), qui fut l'un des premiers à accorder de l'importance au développement des fonctions exécutives en relation avec celui des aires frontales, proposait que ces aires servent à conditionner les processus effectués par le reste du cerveau. Ainsi, il suggérait qu'une lésion de ces aires en bas âge pouvait entraîner une atteinte du développement mental. Levin et al. (1987) et Anderson et Moore (1995) ont démontré que les troubles exécutifs retrouvés suite à un TCE chez l'enfant peuvent interférer avec sa capacité à se développer normalement et à interagir efficacement avec son environnement, entraînant ainsi des troubles du développement cognitif, académique et social.

La présente étude

Notre approche relativement à l'étude des fonctions exécutives durant la période développementale pré-adolescente se démarque de celle des études précédentes puisque nous proposons l'utilisation d'un paradigme qui permet d'évaluer le contrôle endogène par le biais d'une mesure de la reconfiguration des schèmes comportementaux. Ce paradigme permet d'évaluer de façon plus fine et plus spécifique les mécanismes liés au déploiement de la composante intentionnelle de contrôle lors de l'exécution d'une tâche, mécanismes attribués au SSA. De plus, ce paradigme sera utilisé auprès d'une population neurologiquement intacte de même qu'auprès de jeunes ayant subi un traumatisme cranio-encéphalique. Ces derniers montrent de façon caractéristique des difficultés au niveau des fonctions exécutives. L'étude développementale décrite plus loin s'intéresse aux groupes des 11-14 ans et des 15-18 ans. Selon les études développementales citées plus haut, ces deux groupes d'âge sont susceptibles de différer sur le plan de la maturité des mécanismes de contrôle endogène.

OBJECTIFS ET HYPOTHÈSES GÉNÉRALES

La présente étude s'intéresse au contrôle endogène du comportement, soit les mécanismes liés à la composante intentionnelle du contrôle lors de l'exécution d'une tâche, qui est attribué au SSA. On vise particulièrement la mesure de la capacité de reconfiguration, impliquant la modification des schèmes comportementaux nécessaires à la réalisation d'activités à but dirigé. Les participants visés par les travaux constituant la présente thèse sont des adolescents qui sont soit neurologiquement intacts, soit traumatisés cranio-encéphalique.

L'évaluation des mécanismes cognitifs qui nous intéressent sera faite à travers l'utilisation du paradigme de changement de tâches développé par Meiran (1996), que nous avons adapté de façon à le rendre applicable aux populations à l'étude. La mesure critique qui est offerte par ce paradigme est le coût de changement de tâches, c'est-à-dire la différence entre la performance dans une condition où il y a répétition d'une même tâche à deux essais consécutifs, et celle où il y a changement de tâches entre les essais. Ce coût de changement de tâches sera mesuré en fonction des variations 1) de l'intervalle temporel entre la présentation de l'indice de tâche et de la cible à un même essai (intervalle indice-cible; IIC); et 2) de l'intervalle temporel séparant la production d'une réponse à un essai et la présentation de l'indice de tâche pour l'essai suivant (intervalle réponse-indice; IRI). La mesure du coût de changement de tâches en fonction des manipulations des IRI est utilisée à titre de contrôle afin de s'assurer que les résultats obtenus en fonction de variations de l'IIC ne sont pas le reflet des mécanismes d'ajustement rétroactif mais bien de la reconfiguration du schème comportemental.

Hypothèses générales: Étude du développement normal

Les études du développement des fonctions exécutives indiquent que certaines fonctions de planification complexe n'auraient pas encore atteint le niveau de fonctionnement adulte à l'âge de 12 ans et suggèrent ainsi que certains processus exécutifs pourraient poursuivre leur développement durant l'adolescence. La nature du développement des fonctions exécutives se manifestant au cours de l'adolescence demeure cependant mal connue.

De façon congruente aux données comportementales, les observations relatives à la maturation cérébrale des aires pré-frontales indiquent l'occurrence d'un développement neurologique notable entre 11 et 15 ans. Comme il s'agit d'une période du développement encore relativement peu connue, notamment quant à son impact au niveau des fonctions exécutives, nous proposons d'étudier le contrôle endogène lors de cette période du développement, soit chez des adolescents âgés entre 11 et 18 ans.

Nous posons l'hypothèse d'un développement significatif des mécanismes impliqués dans l'alternance et le maintien des schèmes comportementaux entre les âges de 11 et 18 ans. Bien qu'il ne soit pas possible de prédire quels mécanismes seront les plus sensibles au développement, il s'avère possible que seuls certains aspects des processus associés au contrôle comportemental subiront des modifications développementales pendant cette période.

Hypothèses générales: Étude du TCE

Il est clair que le TCE affecte les fonctions exécutives et que cet effet est lié à des atteintes des aires frontales du cerveau. La caractérisation des atteintes exécutives suite à un TCE, et quelquefois même, leur objectivation s'est avérée difficile jusqu'à maintenant. Ces problèmes semblent d'autant plus aigus dans l'étude des populations TCE enfants ou adolescents étant donné d'une part, l'utilisation fréquente de tests relativement peu spécifiques et d'autre part, le fait que les atteintes fonctionnelles sont évaluées avec des épreuves dont on ne connaît pas les caractéristiques lors du développement normal. Dans le but de développer les connaissances relatives à l'atteinte des mécanismes de contrôle endogène chez les jeunes patients TCE, nous avons procédé à trois études de cas d'adolescents TCE avec le paradigme de changement de tâches.

Compte tenu des observations disponibles dans la littérature, nous faisons l’hypothèse d’altérations importantes des mécanismes impliqués dans l'alternance et le maintien des schèmes comportementaux chez les TCE. Nous émettons également l’hypothèse qu’il existera une variabilité dans la nature des atteintes exécutives que peut occasionner le TCE. En particulier, il est attendu que les caractéristiques associées à ces altérations varieront de façon qualitative à travers les individus. Enfin, il est attendu que la nature des dissociations mises en évidence par l'étude des patients appuiera la valeur heuristique et clinique du paradigme de changement de tâches.

THE DEVELOPMENT OF ENDOGENOUS CONTROL DURING ADOLESCENCE STUDIED WITH THE TASK-SWITCHING PARADIGM

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ABSTRACT

The executive process of endogenous control, responsible for the configuration of processing resources into a behavioral schema appropriate for the particular task an individual wishes to perform, was studied in two groups of adolescents aged 11-14 y.o. and 15-18 y.o. According to a task-cue shown prior to the target, participants performed either the same task ('hold' trials) as on the previous trial or a different task ('switch' trials), with a random ordering of this task-switch factor. In Experiment 1, the cue-to-target time interval (CTI) was varied and the interval between the response on a trial and the task-cue for the next trial (RCI) was constant. Task-switch costs (greater RTs and/or error rates on 'switch' than 'hold' trials) were reduced with an increasing CTI. The 11-14 y.o. group showed greater task-switch costs than the 15-18 y.o. group. The younger group also showed longer RTs than the older one, with a gradual reduction of this effect with increasing CTI. In Experiment 2, the RCI was varied while the CTI remained fixed. Variations of the RCI had no systematic impact on task-switch costs. The results of Experiment 2 replicated the greater task-switch costs in the 11-14 y.o group than in the 15-18 y.o. one. The results are discussed in terms of a maturation of the mechanisms involved in endogenous control during adolescence.

INTRODUCTION

Many developmental studies are concerned with executive functions in very young children (Anderson, Lajoie & Bell, 1995; Chelune & Baer, 1986, Passler, Isaac & Hynd, 1985; Welsh, Pennington & Groisser, 1991), but we presently have very little information on the development of these functions during adolescence. The present study is interested in the development of the mechanisms involved in the endogenous control of behavior in adolescents aged between 11 and 18 years old. Endogenous control corresponds to the intentional control component involved in carrying out a particular task, which is attributed to the supervisory attentional system, or central executive (Norman & Shallice, 1986; Rogers & Monsell, 1995). It involves the adaptation of cognitive configurations, also called behavioral schemas or task-sets, with the aim of achieving a particular goal. It thus confers the required flexibility for the adapted expression of behavior according to the demands of the environment.

The development of endogenous control in adolescents will be studied here using the task-switching paradigm, which allows an assessment of the mechanisms involved in the alternation between two behavioral schemas.

BEHAVIORAL ASPECTS OF EXECUTIVE FUNCTIONS

Most authors in the field concur in defining executive functions as an ensemble of interrelated abilities which are necessary to maintain an appropriate problem solving behavior during the willful accomplishment of goal directed activities (Lezak, 1993 ; Stuss & Benson, 1986). Shallice (1988) and Norman & Shallice (1986), specify that these functions are not involved in the accomplishment of routine activities, but rather that they play a fundamental role in novel or unfamiliar situations (i.e. where no routine already exists).

The study of executive functions mainly involves the assessment of goal directed behavior, including planning, structured visual search, and impulsivity control. The study of these behaviors in developmental neuropsychology often rests on the adaptation of neuropsychological tasks originally designed to assess frontal lobe integrity in the adult (Anderson, Anderson et Lajoie, 1996; Becker, Isaac, & Hynd, 1987; Chelune & Baer, 1986; Levin, Culhane, Hartmann, Eankovich, Mattson, Harward, Ringholz, Ewing-Cobbs & Fletcher, 1991; Passler, Isaac & Hynd, 1985; Welsh, Pennington & Groisser, 1991). Other studies essentially aim at establishing developmental norms based on the use of clinical tools designed for the adult (Chelune & Baer, 1986; Kirk & Kelly, 1986; Waber & Holmes, 1985).

The results of developmental studies indicate a sequential improvement of performances in so-called executive tasks (e.g. Passler, Isaak & Hynd, 1985; Welsh, Pennington & Groisser, 1991). The main developmental stages of executive functions suggested by these studies correspond to the ages of 6 and 10 years old, and 12 years old and above, when adult-level abilities gradually emerge (Becker, Isaac & Hynd, 1987 ; Chelune & Baer, 1986; Passler, Isaac & Hynd 1985, Welsh, Pennington & Groisser, 1991). In this respect, some authors have claimed that executive functions would have reached their adult level of operation at the age of 12 years old (Appelof et Augustine, 1986; Chelune et Baer, 1986; Kirk et Kelly, 1986). There are studies however, that suggest otherwise.

For instance, the results of Welsh, Pennington and Groisser (1991) demonstrated that tasks involving simple planning (Hanoi Tower) and visual search were correctly accomplished by 6 year-old children. However, it was only at the age of 10 that capacities of hypothesis evaluation and impulsivity control (as assessed by the Wisconsin Card Sorting Task) seemed to emerge. Finally, 12 year-old children demonstrated performances superior to those of 10 years old. However, these performances did not reach a level comparable to that of the adults in tasks of verbal fluency and motor sequencing as well as in tasks assessing complex planning abilities. These latter results therefore suggest the possibility of an executive function developmental stage occurring during adolescence, that is after the age of 12.

BRAIN DEVELOPMENT AND EXECUTIVE FUNCTIONS

The results of several studies support the hypothesis that the development of executive functions is linked to that of the anterior portion of the brain, and especially of the prefrontal areas. Indeed, the developmental stages evidenced by the results obtained on neuropsychological tasks correlate with those observed in the frontal lobes. (Bell & Fox, 1992; Levin et al, 1991; Thatcher, 1991; 1992; Welsh & Pennington, 1988). Some observations from neurophysiological studies suggest that frontal lobe development may continue beyond the age of 12 years old, which would be compatible with observations from behavioral studies suggesting a continued development of executive functions during adolescence. According to Epstein (1974), three culminating points of brain development would be between the ages of 6 and 8, 10 and 12, and 14 and 16 years old. This is supported by studies of myelination, which may serve as an indicator of the development of the nervous system, demonstrate an increase of the myelination process beyond the age of 15 years old (Fleschsig, 1920; cited in Nowakowski, 1987).

THEORETICAL ASPECTS OF ENDOGENOUS CONTROL

The nature of the resources that are mobilized in the accomplishment of tasks involving executive functions allows an important distinction. On the one hand are functions required for the organization of new tactics, which are involved in the application of strategies and in problem solving. On the other hand are functions necessary for the organization of cognitive and perceptual-motor resources, which allow the expression of adapted behavior as well as to meet the imposed task-constraints at the appropriate time (Rogers & Monsell, 1995). This latter capacity involves the reconfiguration of behavioral schemas as a function of the demands of the task to accomplish, that is conceived as underlying cognitive and behavioral flexibility (Rogers et al., 1998). This stands in opposition to exogenous control, in which the perceptual stimulation available induces the production of behaviors that are associated with them, in spite of the subject's intention.

TASK-SWITCH COSTS AND RECONFIGURATION ABILITIES

The alternation between behavioral schemas assumed to be required when different tasks must be accomplished in sequence involves a cost that can be measured by an increase in reaction times (RTs) and error rates in trials that follow a task-switch compared to performances observed when the same task is maintained across consecutive trials. This difference across conditions is referred to as a task-switch cost. A number of different experimental procedures have been proposed to measure the cost associated with a task-switch (Allport Styles & Hsieh, 1994 ; Jersild, 1927; Meiran, 1996; Rogers & Monsell, 1995).

The paradigm used by Rogers and Monsell (1995) involves an obligatory and preprogrammed task-switch on every other trial within a trial sequence (i.e. "AABBAABB"). Among other things, these authors have studied the effect of variations in the duration of the inter-trial interval on the magnitude of task-switch costs. Their results indicate a significant reduction of task-switch costs with an increase of these time intervals. Thus, during the first 600 msec of the inter-trial interval, the cost associated with a task-switch is reduced by one-third. It then stabilizes itself and remains constant for inter-trial intervals greater than 600 msec.

Rogers and Monsell concluded that the reduction of task-switch costs with increasing inter-trial intervals is associated with the endogenous process of advance reconfiguration of behavioral schemas which would occur within the first 600 msec of this interval. Furthermore, they proposed that whereas the reconfiguration is initiated endogenously, its completion would require an exogenous mechanism triggered by the presentation of the target for the new task.

Thus, there would be a combined and sequential action of endogenous and exogenous control mechanisms. Whereas endogenous control is proposed as responsible for the reduction of task-switch costs with an increased inter-trial interval, exogenous control would account for the stable residual portion of task-switch costs. It should be noted that the results relatively similar to those of Rogers and Monsell have been reported previously by Allport et al. (1994). These latter authors had used a paradigm where the task-switch factor was manipulated across distinct blocks of trials, as opposed to the better controlled within-block manipulation of task-switch used by Rogers and Monsell.

It is the studies of Meiran (1996) that have provided the clearest demonstration of the involvement of executive processes in task-switching. One weakness of the "AABBAABB" paradigm of Rogers and Monsell (and of other task-switching paradigms used by others before them) that was pointed out by Meiran is that this paradigm cannot clearly establish that task-switch costs reflect the need for the advance reconfiguration of behavioral schemas (a true executive process) rather than a proactive interference (or carryover) effect from the different task performed on the previous trial (see Allport et al., 1994; for such an account).

To resolve this ambiguity, Meiran has proposed a new paradigm for the study of task-switching which involves 1) two tasks distributed in a random order within the same block of trials, and 2) the presentation of a task-cue warning the participant of the next task to accomplish prior to the presentation of the target. This experimental format allowed him to independently measure the effects of two distinct components of the inter-trial interval previously studied by Rogers and

Monsell and by Allport et al. These components are the interval separating response production on a trial and the presentation of the task-cue for the next trial (response-to-cue interval; RCI) and the interval between the presentation of the task-cue for a trial and the subsequent onset of the target (cue-to-target interval; CTI), to which the participant must respond.

The joint use of task-cues and of separate manipulations of the RCI and CTI has allowed a clear dissociation between the contributions of the advance reconfiguration of task-sets and of proactive inhibition to task-switch costs. Thus, Meiran's results show a gradual and substantial reduction of task-switch costs with increasing CTI while the total inter-trial interval was kept constant (through a joint manipulation of RCI). This observation indicates that the cost of task-switching cannot be attributed exclusively to a proactive interference effect, which predicts an invariant task-switch cost if the total inter-trial interval (i.e. between a response and the target for the next trial) remains constant. The independent effect of the CTI interval observed by Meiran rather points to an important role of the advance reconfiguration of behavioral schemas in the modulation of task-switch costs. Specifically, the CTI effect suggests that, on task-switch trials, participants initiate the reconfiguration of their task-set at the time of task-cue presentation. The greater the CTI, the more this reconfiguration process is advanced at the time of target onset, therefore causing a reduction of task-switch costs.

TASK-SET RECONFIGURATION DEVELOPMENT

No published developmental study specifically addressing the issue of endogenous control is presently available. However, one study concerned with the reorientation of auditory attention in 8-19 year olds seems relevant (Pearson et Lane, 1991). Thus, Pearson and Lane have demonstrated that increasing age leads to a quantitative improvement of performance in the dichotic listening task. These results thus indicate developmental gains occurring after the age of twelve at the level of processes that seem related to executive functions. This supports the interest of studying the development of executive functions in adolescents beyond the age of twelve.

There are however, very few studies which allow a fine-grained analysis of the developmental period following puberty. Moreover, the presently available studies on executive function development offer no indication regarding the contribution of reconfiguration processes to the development of goal directed behavior.

PRESENT STUDY

The present study examined the development of endogenous control during adolescence. Two experiments using an adaptation of the task-cuing paradigm developed by Meiran (1996) are reported. Both are concerned with the measurement of the cost of switching tasks between consecutive trials in two age groups: 11-14 years old, and 15-18 years old. These ages correspond to developmental plateaus with respect to the ontogenesis of the nervous system (Epstein, 1974).

The first experiment examined task-switch costs as a function of variations of the time interval separating the presentation of the task-cue and of the target (CTI) while the interval separating a response and the task-cue for the next trial (RCI) remained constant. As shown by the studies of Meiran (1996) cited above, this experiment should allow an assessment of the process of advance reconfiguration of behavioral schemas.

In the second experiment, the CTI remained constant whereas the RCI was varied. In this context, an increase of the RCI should lead to a reduction of task-switch costs if they depend (even partially) on proactive interference, as proposed previously by Allport et al. (1994). However, if an increased RCI has no systematic impact on task-switch costs, it will become possible to account for these costs exclusively on the basis of a process of task-set reconfiguration.

EXPERIMENT 1

This experiment measured task-switch costs as a function of the time interval between a task-cue and the subsequent target (cue-to-target-interval, CTI).

It was expected that response times (RTs), and possibly error rates, would be greater when subjects have to switch tasks across consecutive trials than when they perform the same task. This expected difference served as an index of the process of task-set reconfiguration.

In Exp. 1, the use of variable onset intervals between the task-cue and the target (CTI) allowed an assessment of the time-course of task-set reconfiguration following an instruction as to the upcoming task. It was expected that task-switch costs would be largest at the shortest CTI and that they would progressively diminish as the CTI is extended, as reported previously by Meiran (1996).

METHOD

Participants

A total of thirty nine subjects took part in the two experiments reported in this paper. The order in which each experiment was administered to a particular subject was random. Subjects were distributed in two age groups, the 11 to 14 year old group and the 15 to 18 year old group, including respectively 21 and 18 subjects.

Subjects were recruited from a telephone list including five levels of academic grades in a private high school. A short interview was carried out with the parents to verify that the children showed no particular attention problem interfering with school or daily activities, that they had no history of psychiatric or neurological disorders, and that none of them took medication in relation with attention disorders.

All the subjects who took part in this study had normal or corrected visual acuity. Informed written consent was provided by the parents. All subjects were naive as to the purpose of the experiment and none was under any medication having an impact on awareness, attention, or memory. All subjects took part in both Experiments 1 and 2 (described below), which were administered to each subject in a random order.

Materials

The experiment was run on a Macintosh computer equipped with a high resolution screen. Subjects sat at approximately 45 cm from the monitor. The height of the screen was adjusted for each subject so that the fixation point was at eye level. RTs were registered through a voice-key connected to the computer controlling the experiment.

Stimuli

The stimuli serving as targets were a circle and a triangle drawn as outlines. Each was 2 cm high x 2 cm wide.

The stimuli used as task-cues were a triangle within a circle, each drawn in outline (2 cm high x 2 cm wide), and a vertical bi-directional arrow, pointing up and down (2 cm high x 2 cm wide). The former stimulus served to instruct the subject to respond to the shape of the subsequent target (circle or triangle) and the latter to indicate its location (up or down).

All stimuli were shown in black on a white background.

Procedure

Subjects were tested individually in a private room at school in a single session of 45 minutes.

At the beginning of each trial, a task-cue (shape or location) was presented at the center of the screen. The target was then presented after a variable interval following the onset of the cue (cue-to-target interval: CTI; 150, 450, 850, 1550 msec). The target was displayed 2 cm above or below the cue. Both the task-cue and the target remained visible until the subject responded. The time interval separating the subject's response from the onset of the task-cue for the next trial was fixed at 750 msec.

Subjects were instructed to respond verbally in accordance to the task-cue by naming the shape or the location of the target, as rapidly as possible while avoiding errors.

Seven blocks of 65 trials each served for the experiment. The first two blocks (shape and location blocks), randomly administered for each subject, served for training and were not included in the data analysis. Within each training block, the CTI varied randomly across trials but the task-cue remained constant.

After the completion of the training blocks, subjects completed the five experimental blocks. Discounting the first trial of each block, which was neutral with respect to the task-switch factor (i.e. same vs. different tasks across consecutive trials), each experimental block comprised an equal number of trials for each time-interval x task-switch combination which were presented in a random order. A pause of two minutes was given between blocks. The sequence of experimental blocks was administered in a different random order for each individual subject.

The dependent variables were RTs and error rates. The independent variables were Age (11-14 and 15-18 years old), Task-switch (hold vs. switch tasks across consecutive trials), and Cue-to-target interval (CTI: 150, 450, 850, and 1550 msec). The conditions defined by the Task-switch and CTI factors were distributed in equal numbers and in a random order across each experimental block.

RESULTS

The first trial of each block was not included in data analyses since it was neutral with respect to the task-switch factor. The observations from trials in which the subject's answer failed to trigger the microphone were rejected from data analyses. Also, trials on which an error was made were not considered in the RTs analyses. Finally, correct RTs were removed from the data of an individual subject if they were more than three standard deviations away from the subject's mean for that condition. In all these cases, the observations for the following trial are discarded from the data analysis since it was ambiguous with respect to the Task-switch factor. The percentages of discarded trials of each type are reported for each control group in Table 1.

INSERT TABLE 1 NEAR HERE

The correlation between the average correct RTs and error rates was of r(14)= + .65, thus indicating no speed-accuracy trade-off.

Correct RTs and error rates for each condition and age group are shown in Fig. 1 and Table 2, respectively. Correct RTs and error rates were analyzed separately using ANOVA's with Age group (11-14 vs. 15-18 y.o.) as a between-subject factor and Task-switch (hold vs. switch), and CTI (150, 450, 850, and 1550 msec) as repeated measures factors.

INSERT TABLE 2 AND FIG. 1 NEAR HERE

The analysis performed on RTs showed main effects of Age: F (1,37) = 20.3, $p < 0.01$, Task-switch: F (1,37) = 100.2, $p < 0.01$, and CTI: F (3, 111) = 298.4, $p < 0.01$. As seen in Fig. 1, the main effect of age revealed shorter RTs for the older group. With respect to the Task-switch factor, it can also be noted that RTs in the hold condition were shorter than in the switch condition. A reduction of RTs with increasing CTI may also be observed. These main effects were qualified by the two-way interactions of Task-switch x CTI: F (3, 111) = 32.3, $p < 0.01$; Age x Task-switch: F (1, 37) = 4.6, $p < 0.05$; and Age x CTI: F (3, 111) = 8.8, $p < 0.01$. The three-way interaction of Age x Task-switch x CTI was not significant: F (3,111) = 1.80.

The simple effects analysis of the Task-switch x CTI interaction revealed a significant task- switch cost at the four CTI: 150 msec: F(1,37) = 140.79, $p < 0.01$; 450 msec: F(1,37) = 93.26, $p < 0.01$; 850 msec: F(1,37) = 20.12, $p < 0.01$; 1550 msec: F(1,37) = 10.43, $p < 0.01$. However, it can be seen in Fig. 1 that this task-switch cost reduces progressively as CTI increases, which is the cause for the Task-switch x CTI interaction.

Simple effects analysis of the Age x Task-switch interaction showed a significant task-switch cost for both age groups: 11-14 y.o.: F(1,37) = 80.3, $p < 0.01$; 15-18 y.o.: F(1, 37) = 28.59, $p < 0.01$. It can be easily seen in Fig. 1 however, that the task-switch cost is greater in the 11-14 y.o. than in the 15-18 y.o. group, thus causing the Age x Task-switch interaction.

Finally, the simple effect analysis of the Age x CTI interaction revealed that the 11-14 y.o. group had longer RTs than the 15-18 y.o. group at all CTIs; 150 msec: F(1,37) = 28.76, $p < 0.01$; 450 msec: F(1,37) = 23.59, $p < 0.01$; 850 msec: F(1,37) =14.92, $p < 0.01$; 1550 msec: F(1,37) = 10.77, $p < 0.01$. However, inspection of Fig. 1 indicates that the group effect is largest at the shortest CTI and that it progressively decreases with increasing CTIs, which is what caused the Age x CTI interaction to be significant.

The ANOVA performed on error rates showed a main effect of Age group: F(1,37) = 7.76, $p< 0.01$, with the subjects from the 11-14 y.o. group making more errors than those from the 15-18 y.o. group. A main effect of Task-switch: F(1,37) = 34, $p< 0.01$ was also observed, indicating more frequent errors in the switch than the hold condition. The main effect of CTI was not significant: F(3, 111) = 2.60, *n.s.* None of the interactions was significant.

DISCUSSION

The main effects of task-switch observed in Experiment 1 indicate greater RTs and error rates when subjects must perform a task different from that on the previous trial than if consecutive trials involve the same task. Such a task-switch cost has been observed previously in the studies of Jersild (1927), Allport et al (1994), Rogers and Monsell (1995) and Meiran (1996). In the present experiment, as in those of Meiran, this cost of task-switching occurred while the task-switch factor was randomly distributed within blocks of trials and where the task to perform was announced by a task-cue at the beginning of each trial .

The results of Experiment 1 also indicate a global trend of diminishing RTs with increasing CTI. This result may be conceived as reflecting an alerting effect triggered by the task-cue, which also served as a warning signal that the target was going to be presented shortly. This alerting process is defined as a transient mobilization of cognitive resources that improves the individual's capacity to respond to external events (Posner & Boies, 1971).

The progressive reduction of task-switch costs as a function of increasing CTIs demonstrates that subjects are faster in the execution of a task different from that on the previous trial if they have more time available between the presentation of the task-cue and that of the target. This observation suggests a process of advance task-set reconfiguration. Thus, the longer subjects have to adopt the required cognitive configuration for the next task to perform, the closer this configuration is to be ready to insure a proper processing of the target at the time of its onset. These results meet the two criteria stated by Meiran (1996) to support an account of the data in terms of executive functions, which are: the presence of a task-switch cost and the demonstration of proactivity provided by the reduction of task-switch costs with increasing CTI.

It should be pointed out however, that while increasing CTIs lead to a reduction of task-switch costs, this effect seems restricted to short CTIs. Indeed, a separate ANOVA of Task- switch x CTI which was restricted to the intervals of 850 and 1550 msec, failed to show an interaction between those factors : F (1, 37) < 1. This result indicates no reduction of task-shift costs between the CTIs of 850 and 1550 msec. These observations are consistent with those of Rogers and Monsell (1995) obtained in adult subjects, which showed that task-shift costs remain stable when participants have more than 600 msec to reconfigure their task-set. As argued by these latter authors, this suggests that the endogenous reconfiguration of the task-set is initiated during the initial period of this interval. However, the reconfiguration can only be completed through the exogenous control from the target, thus accounting for the residual task-shift cost at the long CTI intervals.

The results of Experiment 1 provide important informations on the cognitive maturation occurring between the ages of 11-14 and of 15-18 years. First, both RTs and error rates reveal a main effect of age demonstrating a superior performance in the older subjects compared to those from the younger group. This improvement of performances with age is qualified however, by the significant interactions of Age x Task-switch and of Age x CTI. These latter observations allow a specification of the processes that seem to have evolved significantly in the 15-18 y.o. group as compared to the 11-14 y.o. group.

Certainly the most important RT data from Experiment 1 with respect to the issue of the development of endogenous control concerns the Age x Task-switch interaction. This interaction indicates weaker task-switch costs in the 15-18 y.o. compared to the 11-14 y.o.

The analysis of RTs from Experiment 1 provided another important observation, which is the interactive effects of Age x CTI. The 11-14 y.o. group consistently shows longer RTs than the 15-18 y.o. group across all CTIs. However, this difference across groups is the greatest at the short CTIs and it gradually decreases with increasing CTI. This result indicates that the mobilization of cognitive resources that is triggered by the task-cue, which also acts as a warning signal, is initiated faster in the 15-18 y.o. group than in the younger subjects, who seem to require more time to reach their optimum alerting level.

EXPERIMENT 2

Experiment 2 measured task-switch costs as a function of the time interval between the subject's response and the presentation of the cue for the next trial (response-to-cue interval; RCI). The aim of this experiment was to examine the specific contribution of proactive interference (see Introduction) in producing task-switch costs and its variation across age groups which was documented in Experiment 1.

METHOD

Participants

As indicated above, the subjects who served in Experiment 1 also served in Experiment 2. The order in which the experiments were administered to a particular subject was determined randomly.

Stimuli, materials and procedure

The stimuli and materials used were the same as in Experiment 1. The procedure was the same as well, with the following exceptions: 1- the cue-to-target interval (CTI) was held constant at 750 msec; 2- the time interval between the subject's response to a particular trial and the presentation of the task-cue for the next trial (response-to-cue interval, RCI) was varied (150, 450, 850, 1550 msec) randomly across trials within blocks. The dependant variables in Experiment 2 were again RTs and error rates. The independent variables were Age (11-14 and 15-18 years old), Task- switch (hold vs. switch tasks across consecutive trials), and Response-to-cue interval, (RCI: 150, 450, 850, and 1550 msec). The conditions defined by the Task-switch and RCI factors were distributed in equal numbers and in a random order across each experimental block.

RESULTS

As in Experiment 1, the first trial of each block was not included in the data analyses since it was neutral with respect to the Task-switch factor.

The observations from trials in which the subject's answer failed to trigger the microphone were rejected from data analyses. Also, trials on which an error was made were not considered in the RTs analyses. Finally, correct RTs were removed from the data of an individual subject if they were more than three standard deviations away from the subject's mean for that condition. These trials that were removed are ambiguous with respect to the subject's task-set. Therefore, in all these cases, the observations from the immediately following trial were also removed from the data analyses. The percentages of discarded trials of each type are reported for each subject group in Table 3.

INSERT TABLE 3 NEAR HERE.

The correlation between correct RTs and error rates was of r(14)= +.73, thus indicating no speed-accuracy trade-off.

Correct RTs and error rates for each condition and age group are shown in Fig. 2 and Table 4 , respectively. These were analyzed separately using an ANOVA with Age group (11-14 vs. 15-18 y.o.) as a between-subject factor and, Task-switch (hold vs. switch), and RCI (150, 450, 850, and 1550 msec) as repeated measures factors.

INSERT FIGURE 2 AND TABLE 4 NEAR HERE

The analysis performed on RTs showed main effects of Age: F(1,37) = 16.3, $p < 0.01$, and Task-switch: F(1,37) = 98.2, $p < 0.01$, but no RCI effect: F(3, 111) = 1.14, ns. As shown in Fig. 2 the 15-18 y.o. group had shorter RTs than the 11-14 y.o. one. With respect to the Task-switch factor, it can also be noted that RTs in the hold condition were shorter than in the switch condition. These main effects were qualified by the two-way interactions of Task-switch x RCI: F(3, 111) = 4.1, $p < 0.01$, and of Age x Task-switch: F(1, 37) = 6.39, $p < 0.05$. The Age x RCI interaction (F < 1) as well as the three-way interaction of Age x Task-switch x CTI were not significant: F(3,111) = 1.04, *n.s.*

Simple effects analysis of the Task-switch x RCI interaction revealed a significant Task-switch cost at each of the four RCI; 150 msec: F(1,37) = 47.8, $p < 0.01$; 450 msec: F(1,37) = 55.7, $p < 0.01$; 850 msec: F(1,37) = 54.44, $p < 0.01$; 1550 msec: F(1,37) = 68.5, $p < 0.01$. No systematic variation of task-switch costs as a function of RCI was observed. Instead, the Task-switch x RCI interaction appears related to the fact that the size of the task-switch cost varies slightly across intervals, but without any systematic pattern. Thus, the mean task-switch costs were of 91, 57, 96 and 75 msec, at the 150 msec, 450 msec, 850 msec and 1550 msec RCIs respectively.

Simple effects analysis of the Age x Task-switch interaction showed a significant Task-switch cost for both age groups; 11-14 y.o.: F(1,37) = 83,8, $p < 0,01$; 15-18 y.o. group: F(1,37) = 25,3, $p < 0,01$. As can be seen in Fig. 2, the task-switch cost was greater in the 11-14 y.o. group (100 msec) than in the 15-18 y.o. group (59 msec), which is responsible for the Age x Task-switch interaction.

The ANOVA performed on error rates showed a main effect of Age: F(1, 37) = 14.8, $p < 0,01$, with subjects from the younger group making more errors than those from the older group. A main effect of Task-switch was also found: F(1,37) = 32.3, $p < 0.01$. Subjects made more errors in the switch condition than in the hold condition. However the effect of RCI was not significant: F(3, 111) = 1.5, *ns*. The two-way interactions Age x Task-switch: F (1, 37) = 11.9, $p < 0,01$, and of Task-switch x RCI: F (3, 111) = 3.8, $p < 0,05$ were also significant. The three-way interaction Age x Task-switch x RCI was not significant: F (3,111) = 1.1, *ns*.

Simple effects analysis of the Age x Task-switch interaction revealed a significant effect of Task-switch only for the younger group: F(1, 37) = 45.3, $p < 0.01$. It can be seen in Table 4 that the switch condition induced more errors than the hold condition in the 11-14 y.o. group.

The simple effects analysis of the Task-switch x RCI interaction revealed that the switch condition induced more errors than the hold condition for the RCIs of 450 msec or longer, but that this effect was not significant with an RCI of 150 msec: 150 msec: F (1,37) = .09, *ns*; 450 msec: F(1,37) = 40, $p < 0.01$: 850 msec: F(1,37) = 6.9, $p < 0.05$; 1550 msec: F (1,37) = 9.6, $p < 0.05$.

DISCUSSION

One important observation from Experiment 2 concerns the effect of task-switching, which indicates longer RTs and greater error rates if the task to be performed is different from that on the previous trial than if it is the same.

Another important observation is that variations of the RCI only had a weak impact on task-switch costs and, most importantly, that this effect was not systematic. Thus, we observe a slight reduction of task-shift costs on the RTs measure at the RCI of 450 msec relative to the others, which do not differ from each other. The weaker task-shift cost at the 450 msec RCI is difficult to interpret and it seems unlikely that it would reflect a significant psychological phenomenon. The same appears to be true with respect to the Task-switch x RCI interaction observed on error rates, which indicated more errors in the task-switch condition than in the hold condition at RCIs of 450 msec and longer but not at the 150 msec RCI.

One major implication of the above findings is that subjects do not seem to spontaneously abandon their current task-set after they have responded to the target. Indeed, had this been the case, we should have expected a systematic reduction of task-shift costs with increasing RCIs. The results rather suggest that the existing task-set remains entirely untouched by the passage of time after a response has been emitted (up to the upper limit of 1550 msec examined here) until the presentation of the next task-cue, upon which the task-set may be reconfigured if a task-switch is required (see Experiment 1).

One final main observation from experiment 2 is the replication of the developmental effects observed in Experiment 1. Thus, in both experiments, subjects from the 15-18 y.o. group showed shorter RTs and smaller error rates than those aged between 11-14 y.o. Moreover, the interaction of Age x Task-switch observed on RTs in Experiment 1 was replicated in Experiment 2. This indicates that the older subject group presents a smaller cost of task-switching than subjects from the 11-14 y.o. group. This latter observation demonstrates the greater effectiveness of the cognitive processes involved in task-set reconfiguration in the 15-18 y.o group than in the 11-14 y.o. group.

GENERAL DISCUSSION

A first aspect of the results suggesting a developmental progress between the 11-14 y.o and the 15-18 y.o. groups are the main effects of Age on correct RTs and error rates in the two experiments. These observations indicate a greater effectiveness in the older group in performing the required tasks.

The most important results from the present study regarding our understanding of the development of endogenous control are provided by the interactions of Age x Task-switch (Experiment 1: on correct RTs; Experiment 2: on correct RTs and error rates) and of Age x CTI (Experiment 1: on correct RTs). The next two sections will offer an interpretation of these results with respect to their implications for the development of executive functions during adolescence.

DEVELOPMENTAL EFFECT ON THE COST OF TASK-SWITCHING

The present study has used an experimental paradigm that is an adaptation of that developed by Meiran (1996). This paradigm is characterized by a random distribution of task-switch vs. hold trials, the use of a task-cue announcing the next task to be performed, and separate manipulations of the response-to-cue (RCI) and cue-to-target (CTI) temporal intervals. Through these features, it avoids the methodological problems associated with other types of task-switch paradigms used prior to Meiran (1996), and it is capable of demonstrating the involvement of the executive process of task-set reconfiguration in the task-switch cost and to distinguish it from effects related to exogenous control and proactive interference (Allport et al., 1994).

The present study demonstrated a task-switch cost consisting in less effective performances (i.e. greater RTs and error rates) if the task to be performed is different from that on the previous trial than if it is the same. An important feature of the task-switch cost observed on RTs is that it diminishes with increasing CTI (Experiment 1), as previously demonstrated by Meiran (1996). Such a result indicates the occurrence of a task-set reconfiguration process following the presentation of a task-cue indicating a task-switch. Specifically, it is proposed that the reconfiguration process is initiated endogenously at the time of presentation of the task-cue and that this process is pursued for a certain time period, as indicated by the reduction of task-switch costs with increasing CTI. In support of this interpretation of the CTI effect on task-switch costs, the results of Experiment 2 show no systematic effect of the RCI on these costs. This indicates that the simple passage of time after the production of a response to a trial has no impact on task-switch costs, thereby implying that these costs are exclusively attributable to a process of reconfiguration of task-set rather than to proactive interference.

In the context of this interpretation of task-switch costs, the observation of a greater cost in the 11-14 y.o. than in the 15-18 y.o. group implies that these groups differ on the effectiveness of the task-set reconfiguration process, a difference which we were able to demonstrate on both correct RTs (Experiments 1 and 2) and error rates (Experiment 2).

Another aspect of the present results which must be underlined is that the cost of task-switching in both groups does not diminish significantly between the CTIs of 850 and 1550 msec (Experiment 1). This observation suggests that the participants to the present study may be similar to the adults studied by Rogers and Monsell (1995) on the duration of the endogenous task-set reconfiguration process. Thus, the latter subjects showed no reduction of task-switch costs with an inter-trial interval greater than 600 msec. Another similarity between the results from the present study and that of Rogers and Monsell (1995) is that significant task-switch costs remain even at intervals beyond those at which the reduction of task-switch costs has stopped. This residual task-switch cost has been interpreted as indicating that exogenous control is necessary to complete the reconfiguration of a task-set, which would take place at the time when the imperative stimulus (i.e. the target) is presented.

DEVELOPMENTAL DIFFERENCES IN THE EFFECT OF CTI

The main effect of CTI observed in Experiment 1 indicates a gradual reduction of correct RTs with an increased CTI. This observation reflects an alerting effect produced by the task-cue, which not only announces the task to perform on the next target, but also serves as a warning signal that the target will be presented shortly. This alerting process, first demonstrated by Posner and Boies (1971), is defined as a transient mobilization of cognitive processing resources that improves the individual's capacity to respond to external stimuli. This translates into a reduction of correct RTs with the increased duration of the warning foreperiod, with error rates either showing no effect or increasing. This kind of observation is observed regularly (including in Meiran, 1996) in many different experimental contexts where a stimulus (visual or auditory) that may act as a warning signal is presented prior to a target requiring a speeded response (see Arguin, Cavanagh and Joanette, 1993; for discussion).

The results of Experiment 1 indicate that the effect of CTI on RTs varies as a function of age group. Specifically, the RT advantage shown by the 15-18 y.o. group over the 11-14 y.o. group is greatest at the shortest CTI, and this advantage gradually reduces with increasing CTI. This observation suggests that the 15-18 y.o. group is better able to maintain a proper level of preparation during the time interval separating the end of a trial (response production) and the beginning of the next (onset of the task-cue), thereby accounting for their shorter RTs at the shortest CTI interval (150 msec). Alternatively, this observation may also mean that subjects from the older group react more quickly to the warning signal (task-cue) in terms of their alerting. One final possibility is that the older group is less sensitive to the uncertainty as to when the target will be presented, which decreases along with an increase in CTI. However, subjects from the 11-14 y.o. group gradually manage to progressively restore their level of preparation to a more appropriate level, thus accounting for the fact that their RTs gradually become closer to those of the 15-18 y.o. group as the CTI increases.

OTHER OBSERVATIONS RELEVANT TO THE COST OF TASK-SWITCHING

Independently of any developmental effect, we note that an increase in the time interval separating the response to a target and the presentation of the task-cue for the next trial (i.e. RCI) has no impact on task-switch costs. In other words, the simple passage of time after responding to a target (within the range of RCIs studied here) fails to affect the task-set that was applied to perform this task.

This indicates that, at the time of task-cue onset, the mental state of subjects corresponds to the task-set for the previous trial. In the case where the task indicated by the task-cue is the same as on the previous trial, subjects would therefore only need to maintain their current task set until the target is presented. Conversely, subjects would begin to abandon their previous task-set and set up a new one of only when the task-cue indicating a task-switch is presented.

This task-set reconfiguration, initiated only at the time of presentation of a task-cue indicating a task-switch, would thus be entirely responsible for the task-switch costs observed. This means that proactive interference has no impact on these costs, contrary to the previous claims of Allport et al. (1994). Indeed, had this been the case, task-switch costs would have been reduced by an increase of the RCI. In his studies, Meiran (1996) demonstrated that task-switch costs are not exclusively attributable to proactive interference by showing that increased CTI led to a reduction of task-switch costs even while the total inter-trial interval (i.e. RCI plus CTI) is constant. The present data therefore, offer an important observation by showing that proactive interference, in fact, does not contribute to task-switch costs at all.

CONCLUSION

The results reported here have demonstrated that the development of endogenous control is pursued during adolescence. Thus, the observations indicate that the mechanisms involved in task-set reconfiguration are immature in adolescents aged between 11-14 y.o. compared to those aged 15-18 y.o. Specifically, it was found that task-set reconfiguration is more effective in the older group of subjects than in the younger one. We also note a difference between groups on the alerting effect, with the younger group providing results suggesting an immaturity in their capacity to maintain an appropriate level of cognitive preparation during the time interval separating two consecutive trials.

The results of the present study therefore demonstrate a developmental progress concerning executive functions beyond the age of 12 years old. This contradicts claims from several previous developmental studied that have argued that executive functions would have reached their adult level of operation at the age of 12 (Appelof et Augustine, 1986; Chelune et Baer, 1986; Kirk et Kelly, 1986).

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TABLES

Table 1

Percentages of discarded trials of each type for the purpose of RTs analyses in Experiment 1.

Group	**Tech problems**	**Errors**	**Outliers**
11-14 y.o	1.6%	5.3%	1.4%
15-18 y.o.	1.8%	3%	1.4%

Table 2

Errors rates (%) for both age groups as a function of task-switch and CTI in Experiment 1.

	11-14 y.o. group		**15-18 y.o. group**	
CTI	**Hold**	**Switch**	**Hold**	**Switch**
150	3.5	6.7	2.3	6.0
450	3.7	6.6	1.6	3.4
850	5.4	6.7	2.0	4.6
1550	3.5	6.4	1.4	2.4

Table 3

Percentages of discarded trials of each type for the purpose of RTs analyses in Experiment 2.

Group	**Tech problems**	**Errors**	**Outliers**
11-14 y.o	1.1%	7.1%	1.9%
15-18 y.o.	1.7%	3.6%	1.6%

Table 4

Errors rates (%) for both age groups as a function of task-switch and RCI in Experiment 2.

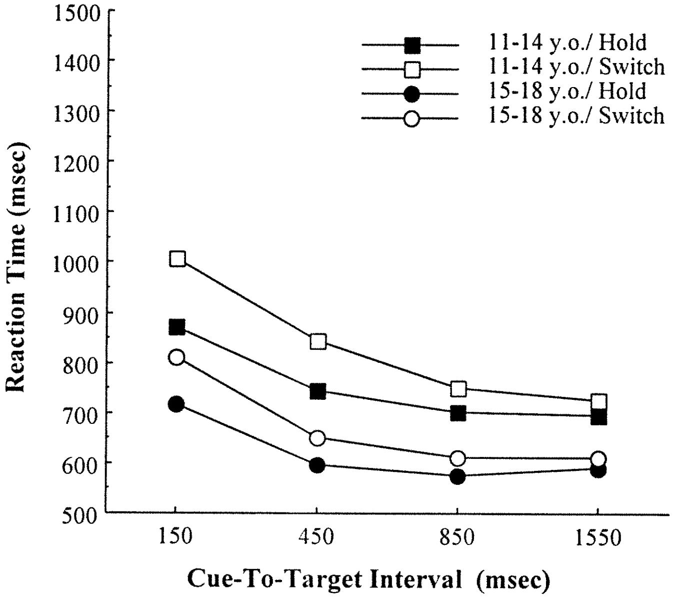
	11-14 y.o. group		**15-18 y.o. group**	
RCI	**Hold**	**Switch**	**Hold**	**Switch**
150	6.6	8.4	4.9	3.6
450	4.8	9.3	1.9	5.8
850	4.4	8.4	2.6	3.5
1550	4.6	9.8	3.2	3.5

FIGURE CAPTIONS

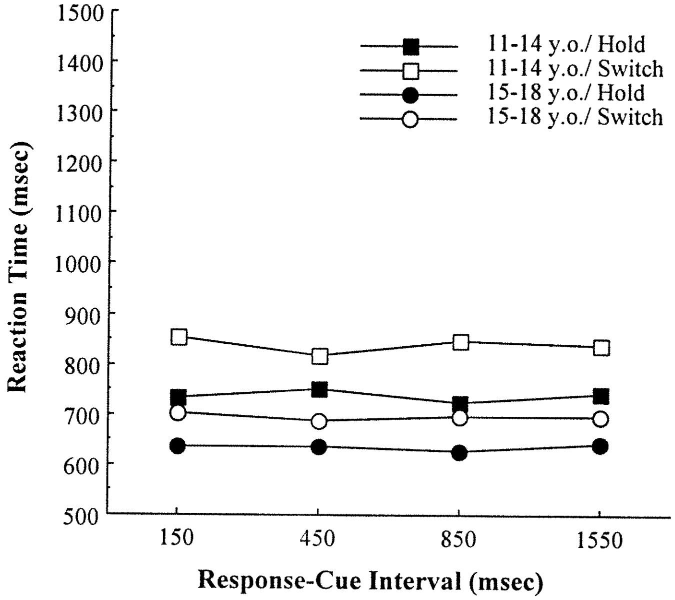
Fig. 1. Correct RTs for the 11-14 y.o. and the 15-18 y.o. groups as a function of task-switch and CTI in Experiment 1.

Fig. 2. Correct RTs for the 11-14 y.o. and the 15-18 y.o. groups as a function of task-switch and RCI in Experiment 2.

FIGURES



Beauchemin et al. – Fig. 1



Beauchemin et al. – Fig. 2

VARIETIES OF ENDOGENOUS CONTROL DEFICITS IN TRAUMATIC BRAIN INJURY ADOLESCENTS

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ABSTRACT

The executive process of endogenous control, responsible for the configuration of processing resources into a behavioral schema appropriate for the particular task an individual wishes to perform, was studied in three patients who had suffered a traumatic brain injury (TBI) and their matched controls. According to a task-cue shown prior to the target, participants performed either the same task ('hold' trials) as on the previous trial or a different task ('switch' trials), with a random ordering of this task-switch factor. In Experiment 1, the cue-to-target time interval (CTI) was varied and the interval between the response on a trial and the task-cue for the next trial (RCI) was constant. In Experiment 2, the RCI was varied while the CTI remained fixed. Normal controls showed task-switch costs (greater RTs and/or error rates on 'switch' than 'hold' trials) which were reduced with an increasing CTI, but that were unaffected by variations of the RCI. Each TBI patient exhibited a specific pattern of major anomalies with respect to control performances. Across cases, these anomalies involved: the absence of a task-switch cost, largely magnified task-switch costs, and the lack of a CTI effect on task-switch costs. These observations suggest varied impairments of endogenous control following TBI and specify a number of endogenous control mechanisms in normal cognition.

INTRODUCTION

Traumatic brain injury (TBI) causes a sudden change of consciousness of a duration and severity which vary across individuals. The cognitive deficits associated with TBI may be severe and persistent (Brink, Garrett, Hale, Woo-Sam & Nickel, 1970; Craft, Shaw & Cartlidge, 1972; Dalby & Obrzut, 1991; Jennet & Bond, 1975) and they often involve a more or less severe alterations of attentional and executive processes (Anderson, 1998).

The present study is concerned with endogenous control in adolescents who have suffered a TBI. Endogenous control corresponds to the intentional control component involved in carrying out a particular task, which is attributed to the supervisory attentional system, or central executive (Norman & Shallice, 1986; Rogers & Monsell, 1995). It involves the adaptation of cognitive configurations, also called behavioral schemas or task-sets, with the aim of achieving a particular goal. It thus confers the required flexibility for the adapted expression of behavior according to the demands of the environment. The particular relevance of studying endogenous control in TBI adolescents is that this process may not only be affected in its operation, but also in its development, and this has general negative consequences for cognitive and mnestic abilities (Levin, Culhane, Hartmann, Evankovich, Mattson, Harward, Ringholz, Ewing-Cobbs & Fletcher, 1991). Indeed, our previous studies have demonstrated that the development of endogenous control is pursued during adolescence, i.e. between the ages of 11 and 18 y.o. (Beauchemin, Arguin and Belleville, 2002).

Endogenous control in TBI adolescents will be assessed here using a task-switching paradigm, which requires the alternation between task-sets.

In the following paragraphs, we will first define executive functions and review studies pertaining to the development of these functions. We will then discuss relevant issues regarding TBI, in particular problems related to brain lesions in youth and their impact on executive functions. We will then make a theoretical review of endogenous control and its operationalization. The results from three TBI adolescents in a task-switching paradigm will then be reported and compared to those of their matched control groups. These observations will finally be interpreted in terms of specific impairments of endogenous control. These impairments, it will be argued, have implications for our understanding of the operation of the endogenous control system in the normal brain.

EXECUTIVE FUNCTIONS

Most authors in the field concur in defining executive functions as an ensemble of interrelated abilities which are necessary to maintain an appropriate problem solving behavior during the willful accomplishment of goal directed activities (Lezak, 1983 ; Stuss & Benson, 1986). Shallice (1988) and Norman & Shallice (1986) specified that these functions are not involved in the accomplishment of routine activities, but rather that they play a fundamental role in novel or unfamiliar situations (i.e. where no routine already exists).

DEVELOPMENTAL ASPECT OF EXECUTIVE FUNCTIONS

The study of executive functions mainly involves the assessment of goal directed behavior, including planning, structured visual search, and impulsivity control. The study of these behaviors in developmental neuropsychology often rests on the adaptation of neuropsychological tasks originally designed to assess frontal lobe integrity in the adult (Anderson, Anderson & Lajoie, 1996; Becker, Isaac, & Hynd, 1987; Chelune & Baer, 1986; Levin et al, 1991; Passler, Isaac & Hynd, 1985; Welsh, Pennington & Groisser, 1991). Other studies essentially aim at establishing developmental norms based on the use of clinical tools designed for the adult (Chelune & Baer, 1986; Kirk & Kelly, 1986; Waber & Holmes, 1985).

The results of developmental studies indicate a sequential improvement of performances in so-called executive tasks (Passler et al., 1985; Welsh et al., 1991). The main developmental stages of executive functions suggested by these studies correspond to the ages of 6 and 10 years old, and 12 years old and above, which would correspond to when adult-level abilities gradually emerge (Becker et al., 1987 ; Chelune & Baer, 1986; Passler et al., 1985, Welsh et al., 1991). For instance, the results of Welsh et al. (1991) demonstrated that tasks involving simple planning (Hanoi Tower) and visual search were correctly accomplished by 6 year-old children. However, it was only at the age of 10 that capacities of hypothesis evaluation and impulsivity control (as assessed by the Wisconsin Card Sorting Task) seemed to emerge. Finally, 12 year-old children demonstrated performances superior to those of 10 years old. However, these performances did not reach a level comparable to that of the adults in tasks of verbal fluency and motor sequencing, as well as in tasks assessing complex planning abilities. These latter results therefore suggest the possibility of an executive function developmental stage occurring during adolescence, that is after the age of 12.

TRAUMATIC BRAIN INJURY

The diffuse cerebral damage particularly associated with TBI almost invariably affects the frontal lobes, as demonstrated by cerebral magnetic resonance imaging and evoked potentials (Langfitt et al, 1986; Levin Goldstein, Williams & Eisenberg, 1987; Levin, Goldstein, Williams & Eisenberg, 1991). Congruently, many authors have documented the appearance of executive and attentional deficits in TBI individuals (Conkey, 1938; Dencker & Lofving, 1958; Goldstein, 1952; Gronwall & Sampson, 1974; Gronwall & Wrightson, 1974; MacFlynn, Montgomery, Fenton & Rutherford, 1984; Meyer, 1904; Ruesch, 1944; Van Zomeran, 1981; Van Zomeran & Deelman, 1976;), symptoms known to be common in cases of focal frontal lesions .

Severe behavioral alterations are often observed in TBI but some of these may disappear a number of weeks or months after the traumatic event. However, self-regulation deficits suggesting a so-called "frontal" clinical portrait, also referred to as a dysexecutive syndrome, may persist several years after the TBI (Goldberg, Bilder, Hugues et al, 1989; Lezak, 1983; Luria, 1980; Van Zomeran, Brouwer & Deelman, 1984). This dysexecutive disorder is defined as a problem affecting the formulation of intention and the organization of the elementary behaviors necessary for achieving a particular goal (Luria, 1973), abilities which would also be necessary for an appropriate and socially acceptable conduct (Damasio, 1985; Fuster, 1989; Stuss & Benson, 1986). In terms of the observable behavior, the dysexecutive syndrome may manifest itself through disinhibition, perseveration, difficulties in initiating appropriate behaviors, in maintaining attention and effort, in recognizing and using feedback information, or in the modulation of independent activities (Benton, 1991; Evankovitch, Levin, Mattson, Fletcher & Ewing-Cobbs, 1990; Mateer & Williams, 1991;). Problems affecting planning, problem solving, and behavioral adaptation may also be present (Anderson, 1998).

BRAIN LESIONS IN YOUTH

Russell (1948) was one of the first to signal the importance of the development of executive functions in relation to the frontal areas of the brain. In particular, he proposed that these areas would serve to condition the behavioral schemas applied by the rest of the brain. He also suggested that lesions affecting the frontal lobes at an early age could lead to a general impairment of mental development. More recently, Dennis (1989), Levin et al. (1991), as well as Anderson and Moore (1995) have all demonstrated that the executive deficits observed following a TBI in children may interfere with their development and with their capacity to interact effectively with their environment, thereby leading to generalized problems in their cognitive, academic, and social development.

TRAUMATIC BRAIN INJURY AND EXECUTIVE FUNCTION DEFICITS

The study of executive functions in children with TBI still little developed. Thus, very few studies have investigated executive deficits in TBI children and, most often, the assessment tools used have been created originally for an adult population (Cooley et Morris, 1990). Moreover, the tests used offer an analysis which is not sufficiently detailed to allow an appropriate measurement of the cognitive components that are investigated. Finally, the type of executive function studied is seldom defined systematically and it is often confounded with the definition of attentional processes.

Still, the literature on children or adolescents with TBI demonstrates behavioral deficits compatible with the hypothesis of an executive function disorder. Thus, it may be noted that the time required to administer tests in young TBI subjects is significantly increased compared to neurologically intact individuals, and the severity of this problem seems to be a function of the level of difficulty of the task. Clinical observations also indicate that TBI children are often distracted from their activities by interference coming either from their own thoughts or from environmental stimulation that they fail to inhibit. These latter observations suggest a tendency towards impulsivity comparable to that observed in patients with focal frontal damage.

The notion of divided attention corresponds to the distribution of attentional resources across two or more information sources. Most authors agree that there is a dramatic deterioration of divided attention in TBI patients. In fact, this would be the main attentional deficit suffered by adult TBI individuals (Gray, 1990; Van Zomeran & Brouwer, 1990). For instance, Gronwall and Sampson (1974) have reported a performance deterioration when simultaneous activities of listening, calculating, and of verbal response production, must be performed at a rate of one digit per second instead of one per three seconds. Similarly, Gentilini, Nichelli & Shoenhuber (1986) have reported a significant reaction time (RT) increase under dual-task conditions in TBI subjects, assessed one month after the accident, compared to control subjects. Thus, TBI subjects performed as their neurological controls when counting backwards or when performing a digit cancellation task on their own. However, when these two tasks must be accomplished simultaneously, the increase in reaction times is substantially greater in the TBI group than in normal controls.

TBI subjects also generally demonstrate a dramatic increase of their response times and error rates as a function of the number of alternatives in choice RT tasks (Gronwall & Sampson, 1974; Miller, 1970; Van Zomeran & Deelman, 1976). It has been suggested that the severity of this deficit is proportional to the duration of coma. These observations imply a slowing of information processing and decision-making in TBI patients. These may also correspond to a difficulty in the configuration of different responses in tasks where many alternatives are available.

Theoretically, this phenomenon would be linked to a deficit of endogenous control, with exogenous control conversely exerting a great influence on behavior (e.g. utilization behavior, perseveration, capture errors; Rogers & Monsell, 1995). Even though the study of executive functions is currently a popular topic, few tasks offer a clear operationalization of the different mechanisms that may be conceived as being part of the executive functions.

THEORETICAL ASPECTS OF ENDOGENOUS CONTROL

Endogenous control concerns the functions required for the organization of cognitive and perceptivo-motor resources allowing the expression of behaviors that are adapted to the individual's goals and to the environmental constraints. Specifically, endogenous control is defined by the assembly of perceptive, cognitive, and response processes which, once properly arranged, will allow the individual to meet the behavioral demands imposed by a particular situation at the required moment (Rogers & Monsell, 1995). This capacity to reconfigure behavioral schemas, or task-sets, as a function of the demands of what has to be accomplished is conceived as underlying cognitive and behavioral flexibility (Rogers & Monsell, 1995). This stands in opposition to exogenous control, in which the perceptual stimulation available induces the production of behaviors that are associated with them in spite of the subject's intention (as in utilization behavior, perseveration, and capture errors; Rogers & Monsell, 1995).

THE COSTS OF TASK-SWITCHING

The alternation between task-sets that is required in the accomplishment of different tasks in sequence is accompanied by a performance cost which may be measured by an increase in RTs and error rates on trials involving a task-switch compared to performance when consecutive trials involve the same task. This difference across conditions is referred to as a task-switch cost. A number of different experimental procedures have been proposed to measure the cost associated with a task-switch (Allport Styles & Hsieh, 1994; Jersild, 1927; Rogers & Monsell, 1995; Meiran, 1996).

Rogers and Monsell (1995) used a paradigm involving an obligatory and preprogrammed task-switch on every other trial within a trial sequence (i.e. "AABBAABB"). They also studied the effect of variations in the duration of the inter-trial interval on the magnitude of task-switch costs. A significant reduction of task-switch costs with an increase of these time intervals was found, where the cost associated with a task-switch is reduced by one-third in the first 600 msec of the inter-trial interval and then stabilizes itself and remains constant for inter-trial intervals greater than 600 msec.

They concluded that within the first 600 msec the reduction of task-switch costs with increasing inter-trial intervals is associated with the endogenous process of advance reconfiguration of behavioral schemas and its completion would require an exogenous mechanism triggered by the presentation of the target for the new task. Thus, there would be a combined and sequential action of endogenous and exogenous control mechanisms.

It should be noted that Allport et al. (1994) previously reported results relatively similar to those of Rogers and Monsell where the task-switch factor was manipulated across distinct blocks of trials, as opposed to the better controlled within-block manipulation of task-switch used by Rogers and Monsell.

Meiran's (1996) studies using the task-switching paradigm are certainly those that have provided the clearest demonstration of the involvement of executive processes in task-switching. Thus, Meiran pointed out that the "AABBAABB" paradigm of Rogers and Monsell (and of other task-switching paradigms used by others before them) cannot clearly establish that task-switch costs reflect the need for the advance reconfiguration of behavioral schemas (a true executive process) rather than a proactive interference (or carryover) effect from the different task performed on the previous trial (see Allport et al., 1994; for such an account).

Meiran proposed a new paradigm for the study of task-switching which involves 1) two tasks distributed in a random order within the same block of trials, and 2) the presentation of a task-cue warning the participant of the next task to accomplish prior to the presentation of the target. This experimental format allowed him to independently measure the effects of two distinct components of the inter-trial interval previously studied by Rogers and Monsell and by Allport et al. These components are the interval separating response production on a trial and the presentation of the task-cue for the next trial (response-to-cue interval; RCI) and the interval between the presentation of the task-cue for a trial and the subsequent onset of the target (cue-to-target interval; CTI), to which the participant must respond.

A clear dissociation between the contributions of the advance reconfiguration of task-sets and of proactive inhibition to task-switch costs was then possible with the joint use of task-cues and of separate manipulations of the

RCI and CTI. A gradual and substantial reduction of task-switch costs was observed with increasing CTI while the total inter-trial interval was kept constant (through a joint manipulation of RCI). This observation indicates that the cost of task-switching cannot be attributed exclusively to a proactive interference effect, which predicts an invariant task-switch cost if the total inter-trial interval (i.e. between a response and the target for the next trial) remains constant. The independent effect of the CTI observed by Meiran rather points to an important role of the advance reconfiguration of behavioral schemas in the modulation of task-switch costs. Specifically, the CTI effect suggests that, on task-switch trials, participants initiate the reconfiguration of their task-set at the time of task-cue presentation. The greater the CTI, the more this reconfiguration process is advanced at the time of target onset, therefore causing a reduction of task-switch costs.

PRESENT STUDY

In the present study, the task-switching paradigm proposed by Meiran (1996) was used to study endogenous control in TBI adolescents. The frequent observation of behavioral organization problems that are compatible with an executive function deficit in TBI as well as the usual occurrence of frontal lesions in this population predicts an alteration of endogenous control in our brain-damaged patients.

Two experiments are proposed which measured the cost of task-switching across consecutive trials in three TBI adolescents and their matched control subjects.

The first experiment examined task-switch costs as a function of variations of the time interval separating the presentation of the task-cue and of the target (CTI), while the interval separating a response and the task-cue for the next trial (RCI) remained constant. As shown by the studies of Meiran cited above, this experiment should allow an assessment of the process of advance task-set reconfiguration.

In the second experiment, the CTI remained constant whereas the RCI was varied. In this context, an increase of the RCI should lead to a reduction of task-switch costs if they depend (even partially) on proactive interference, as proposed previously by Allport et al. (1994). However, if an increased RCI has no systematic impact on task-switch costs, it will become possible to account for these costs exclusively on the basis of a process of reconfiguration of behavioral schemas.

The objectives of the research reported here are twofold. First, it aims to document the nature and variety of the deficits that may affect endogenous control following a TBI and to assess the relevance of the task-switching paradigm for the clinical evaluation of these deficits in adolescents who have suffered a TBI. Secondly, a specification of the deficits that may affect endogenous control following brain damage will contribute to our knowledge regarding the organization of this system in the neurologically intact individuals.

EXPERIMENT 1

Experiment 1 used the type of experimental design proposed by Meiran (1996) to examine task-switch costs as a function of the time interval between a task-cue and a subsequent target (cue-to-target-interval, CTI). It was expected that response times (RTs), and possibly error rates, would be larger when subjects have to switch tasks across consecutive trials than when they perform the same task. This expected difference served as an index of the task-set reconfiguration process.

In Exp. 1, task-switch costs were measured at different onset intervals between the task-cue and the target (CTI) in order to determine the time course of task-set reconfiguration. It was expected that the task-switch cost would be the largest at the shortest CTI, and that it would then progressively diminish as the CTI is extended.

METHOD

Participants

This study focused on three adolescents who have suffered from a traumatic brain injury. Control groups matched to the TBI subjects according to their age served as reference as to the normal performance in the experiments. All subjects took part to both of the reported experiments. The data used for the control group are issued from a developmental study with the same subjects.

Brain damaged subjects

The three experimental subjects had suffered a moderate to severe TBI and were recruited during their rehabilitation phase at the Hôpital de Réadaptation Marie-Enfant in Montreal. Participants were tested at the research laboratory of that institution during periods of the day when they were not receiving any treatment.

Each TBI participant had academic grades above the average and showed no particular attentional problems prior to their accident.

MB, aged 12 y.o., had been involved in an automobile accident one month prior to testing. At the time of the accident, she was given a score of 3 on the Glasgow coma scale and she had a coma of a duration of 48 hours. The medical file indicates a brain contusion of the left fronto-temporal area

PLD, also aged 12 y.o., was a victim of an automobile accident. He took part in the present experiments three months post-trauma. At the time of the accident, he received a score of 5 on the Glasgow scale and he suffered a 7-day coma. His medical file indicates the presence of brain damage in the left temporo-parietal area and bilateral frontal lesions.

POB, aged 14 y.o., was seen three months after an alpine skiing accident. At the time of the accident, he was given a score of 5 on the Glasgow scale and he was in a coma for a duration of 48 hours. The medical file reports brainstem damage as well as a left frontal epidural hematoma.

Neurological controls

Each of the TBI subjects was compared to his/her own age-matched neurological control group. Control group 1 included 10 subjects aged 11 or 12 y.o. and served for comparison against TBI subjects PLD and MB. Control group 2 comprised 11 subjects aged 13 or 14 y.o. whose performances served as the standard for comparison for patient POB.

Neurological control subjects were recruited from a telephone list including five levels of academic grades in a private high-school. A short interview was carried out with the parents to verify that the children showed no particular attention problem interfering with school or daily activities, that they had no history of psychiatric or neurological disorders, and that none of them took medication in relation with attention disorders.

All the subjects who took part in this study had normal or corrected visual acuity. Informed written consent was provided by the parents. All subjects were naive as to the purpose of the experiment and none was under any medication having an impact on awareness, attention, or memory. All subjects took part in both Experiments 1 and 2 (described below), which were administered to each subject in a random order.

Materials

The experiment was run on a Macintosh computer equipped with a high resolution screen. Subjects sat approximately at 45 cm from the computer screen. The height of the screen was adjusted for each subject so that the fixation point presented at the center of the screen was at eye level. RTs were registered through a voice-key connected to the computer controlling the experiment.

Stimuli

The stimuli serving as targets were a circle and a triangle which were drawn as outlines. Each was 2 cm high x 2 cm wide.

The stimuli used as task-cues were a triangle within a circle, each drawn in outline (2 cm high x 2 cm wide), and a bi-directional arrow pointing up and down (2 cm high x 2 cm wide). The former stimulus served to instruct the subject to respond to the shape of the subsequent target (circle or triangle) and the latter to indicate its location (up or down).

All stimuli were shown in black on a white background.

Procedure

Control subjects were tested individually in a private room at school during a single 45-minutes session. Patients were tested in a research laboratory of the Hôpital Marie-Enfant.

Each trial began with the task-cue (shape or location) which was presented at the center of the screen. The target was then presented after a variable time interval (cue-to-target interval, CTI: 150, 450, 850, 1550 msec) following the onset of the task-cue. The target was a circle or a triangle and it was displayed 2 cm above or below the cue. Both the task-cue and the target remained visible until the subject responded. The time interval between the subject's response and the task-cue for the next trial (response-to-cue interval, RCI) was fixed at 750 msec.

Subjects were instructed to respond verbally in accordance to the task-cue by naming the shape (circle or triangle) or the location (up or down) of the target, as rapidly as possible while avoiding errors.

The independent variables were Task-switch (hold vs. switch tasks across consecutive trials), and the Cue-to-target interval (CTI: 150, 450, 850, and 1550 msec). The dependent variables were RTs and error rates. The task-set reconfiguration capacity was estimated from the performance difference between the trials where the task to perform was the same as on the preceding trial vs. those where the task was different.

The experiment was administered in seven blocks of 65 trials each. The first two blocks served for training and were not included in the analysis. In the first training block subjects were required to respond to the shape of the target on every trial whereas in the second block, they always responded to the location of the target. After the practice blocks, subjects received the five experimental blocks. Discounting the first trial of each block, which was neutral with respect to the Task-switch factor (i.e. same vs. different tasks across consecutive trials), each experimental block comprised an equal number of trials for each Cue-to-target interval x Task-switch combination which were presented in a random order. The order of the five experimental blocks was determined randomly. A pause of two minutes was taken between blocks.

RESULTS

The first trial of each block was rejected from the data analyses since it was neutral with respect to the Task-switch factor. The reaction times (RTs) associated with trials in which the subject's answer failed to trigger the microphone were discarded from data analysis, as were the errors. Outlier RTs were also removed from the data of an individual subject if they were more than three standard deviations away from the subject's mean for that condition. In all these cases, the observation for the following trial was also discarded from the data analyses since it was ambiguous with respect to the Task-switch factor.

The correlations between correct RTs and error rates for the control groups and individual TBI cases were all positive or, if negative, were not significant. These observations indicate the absence of a speed-accuracy trade-off. These correlation and the percentages of discarded trials of each type are reported for each control group and each TBI subject in Table 1.

INSERT TABLE 1 NEAR HERE

Control groups

Correct response times (RTs) for Control groups 1 and 2 are shown respectively in Figs. 1 and 2, and errors rates are shown in Table 2. RTs and errors rate were analyzed separately using ANOVAs with CTI (150, 450, 850, or 1550 msec) and Task-switch (hold vs. switch) as within-subject-factors.

INSERT FIGS. 1 AND 2 AND TABLE 2 NEAR HERE

In both control groups, the analysis of RTs showed significant main effects of Task-switch : group 1: F(1, 9) = 17.9, $p < 0.01$; group 2: F(1,10) = 59.3, $p < 0.01$ and of CTI : group 1: F(3, 27) = 75.4, $p < 0.01$; group 2: F(3,30) = 89.3, $p < 0.01$. As shown in Figs. 1 and 2, these main effects indicate longer RTs in the switch than the hold condition and decreasing RTs with increased CTI. Both control groups also showed a significant Task-switch x CTI interaction : group 1: F(3, 27) = 4.4, $p < 0.05$; group 2: F(3, 30) = 16.3, $p < 0.01$. This latter result indicates a progressive reduction in the Task-switch cost with increasing CTI. In other words, both groups benefited from an increased CTI with respect to their task-switch costs. As demonstrated in Beauchemin et al. (2001), this effect was found in two age groups of adolescents (11-14 and 15-18 y.o.), and was interpreted as an index of the task-set reconfiguration process following the presentation of the task-cue on task-switch trials (Meiran, 1996).

The simple effects analysis of the Task-switch x CTI interaction revealed a significant task-switch cost at the two shortest CTIs, but not at the longest two for Control group 1 : 150 msec : F(1,9) = 23.9, $p < 0.01$; 450 msec : F(1,9)= 15.9, $p < 0.01$; 850 msec : F(1,9) = 3.14, n.s.; 1550 msec : F(1,9) = 4.8, n.s., and a significant Task-switch cost at the three shortest CTI but not at the longest one for Control group 2 : 150 msec : F(1,10) = 50, $p < 0.01$; 450 msec : F(1,10) = 72.9, $p < 0.01$; 850 msec : F(1,10) = 8.1, $p < 0.05$; 1550 msec : F(1,10) = 2.6, n.s.

The analysis performed on the error rates of both control groups revealed a main effect of Task-switch : group 1 : F(1, 9) = 15.5, $p < 0.01$; group 2 : F(1,10) = 7.1, $p < 0.05$, but no main effect of CTI : group 1 : F(3, 27) = 0.6, n.s. ; group 2 : F(3, 30) = 0.16, n.s. and no Task-switch x CTI interaction : group 1 : F(3, 27) = 0.64 n.s.; group 2 : F(3, 30) = 0.28, n.s. For both groups, the main effect of Task-switch indicates more errors in the switch than in the hold condition.

Brain damaged subjects

An ANOVA was performed on each patient correct individual RTs. MB's results are in striking contrast to those of her normal controls (Control group 1). Whereas MB showed a significant reduction of RTs with increasing CTI : F(3, 294) = 57.5, $p < 0.01$, her results indicated no significant effect of Task-switch : F(1, 294) = 0.19, n.s. < 1] and no interaction of this factor with CTI : F(3, 294) = 2.4, *n.s.* Across CTIs, the average task-switch cost shown by MB was of -8 msec (Fig. 3). The analyses performed on error rates (overall average error rate of 0.6%) for MB showed no significant effect.

INSERT FIG. 3 NEAR HERE

Both patients POB and PLD showed significant main effects of Task-switch on their correct RTs (see Figs. 4 and 5): POB: F(1, 283) = 9.8, $p < 0.01$; PLD: F(1, 229) = 56.7, $p < 0.01$, and of CTI : POB: F(3, 283) = 21.8, $p < 0.01$; PLD: F(3, 229) = 14.0, $p < 0.01$, similar to those found in their respective normal control group (Figs. 1 and 2). In contrast to normal controls however, POB and PLD showed no Task-switch x CTI interaction : POB: F(3, 283) < 1; PLD: F(3, 229) < 1. This indicates that task-switch costs in these patients were not reduced with an increased CTI. Importantly the abnormal absence of the Task-switch x CTI interaction in POB and PLD appears not to be a function of the magnitude of their task-switch costs. Indeed, POB showed task-switch costs that are within the range of those shown by his matched controls, none of them exceeding ±1.2 standard deviations away from the normal mean. Notably however, PLD exhibited abnormally large task-switch costs at all CTIs : z-scores of 5.44, 6.05, 4.19, and 4.39; $p < 0.001$ for CTIs of 150, 450, 850 and 1550 msec, respectively.

INSERT FIGS. 4 AND 5 NEAR HERE

The analyses performed on error rate for POB (overall average of 3.4 %) and PLD (overall average of 9 %) showed no significant effect for POB, but a significant task-switch cost for PLD: Total χ^2 (3)= 2.8, n.s.; Task : χ^2 (1)= 9.1; Interval: χ^2 (3)= 1.4, n.s., which indicates fewer errors in the hold than the switch condition.

The correlation between task-switch costs and RTs in the Hold condition were all negative and if positive, were not significant. These observations reveal that there is no relation between the magnitude of the task-switch costs and the general slower RT in the younger in comparison to the older.

DISCUSSION

The results from both normal control groups indicate a significant task-switch cost on the RTs and error rate measures. Thus, both RTs and error rates are greater on switch than on hold trials. This task-switch cost indicates that when there is a task-switch across consecutive trials, a modification of the task-set configuration must be carried out, which is not required if consecutive trials involve the same task (see also Meiran, 1996). Importantly, however, the task-switch cost on RTs shows a marked and monotonic reduction with increasing CTI. This suggests that, when they must switch tasks across consecutive trials, neurologically intact subjects begin to reconfigure their task-set rapidly after the onset of the cue (Beauchemin et al. 2002; Meiran, 1996). This advanced reconfiguration proceeds through time so that, with an increased interval between the task-cue and the target, the subject's task-set is brought closer to that required to appropriately process the target. These results and interpretations are in agreement with those previously reported by Meiran (1996) and by Rogers and Monsell (1995).

The results from the TBI subjects in Exp. 1 reveal three dissociable classes of anomalies that may affect task-set and its reconfiguration in brain-damaged individuals. One is the lack of task-switch cost observed in MB, which contrasts with the significant costs noted in the neurologically intact controls. Another anomaly, shared by PLD and POB is the maintained magnitude of task-switch costs across the full extent of CTIs examined in the present experiment. This is different from the neurological controls, who showed a reduction of task-switch costs with increasing CTI. Finally, another deviant performance feature observed in the present brain-damaged sample is the largely magnified task-switch cost in PLD as compared with his matched controls. These three dissociable patterns of impairments are discussed in turn below.

The results from patient MB indicate that she differs from the neurologically intact control participants by her lack of a task-switch cost. It is unlikely that the brain-damage suffered by MB has made her more effective with respect to executive function. Instead, it is argued that the absence of a task-switch cost in MB points to a severe alteration of executive function. Thus, task-switch costs in normal subjects are assumed to result from the fact that task-set is spontaneously maintained from one trial to the next, and thus that a reconfiguration of task-set is required on task-switch trials. Evidence supporting this assertion has been reported by Beauchemin et al. (2002) in a study that manipulated CTI and response-to-cue intervals independently (see also Meiran, 1996; for relevant observations). It has shown that task-switch costs are largely maintained in their magnitude through variations in the time interval separating the response to the target on a particular trial and the beginning (with the presentation of the task-cue) of the following trial. Congruent evidence will also be reported in Exp. 2. Taken together with the CTI effect shown here in normal controls, this indicates that task-switch costs only start to decline substantially when the task-cue initiating a trial is displayed. At that time, subjects may begin reconfiguring their task set if the task-cue indicates a task different from that of the previous trial.

In this context, the complete lack of task-switch cost in MB appears to result from an incapacity of the patient in maintaining her task-set during the time interval that separated trials (i.e. the 750 msec delay occurring between the subject's response and the onset of the task-cue for the next trial). In other words, it is assumed that, in contrast to neurologically intact observers, MB lacked a configured task-set when the task-cue was presented at the beginning of a trial. Because of this absence of an already configured task-set, switch and hold trials were no different for MB, who always had to configure her task-set anew upon the presentation of the task-cue. The impairment in maintaining a task-set exhibited by MB is reminiscent of the frequent difficulty of patients with frontal damage in staying focused on the task in progress (Benton, 1991; Evankovitch et al, 1990; Mateer & Williams, 1991).

In contrast to normal controls, POB and PLD entirely failed to benefit from an increased CT interval to reduce their task-switch costs. This suggests that these two brain-damaged subjects are incapable of reconfiguring their task-set based on the presentation of the task-cue alone. Rather, they appear to remain passive with respect to their task-set until the target is presented. Only at that time do they seem to deploy any of the task-set reconfiguration activity that is required to eventually be able to properly respond to the target in the switch condition. Since POB and PLD both fail to reconfigure their task-set in advance on task-switch trials, it is proposed that their reconfiguration is initiated through the exogenous control of the target rather than endogenously, as in the normal controls.

The failure of advanced reconfiguration exhibited by both POB and PLD, obviously implies a functional impairment different from that noted above for MB, who appeared incapable of maintaining her task-set after her response to the target was emitted. Less obviously but just as importantly, the failure of advance task-set reconfiguration in POB and PLD is also dissociable from an anomaly in the magnitude of task-switch costs, as discussed in the next section.

The magnitude of the task-switch cost that is observed at a particular CT interval may be considered as an index of how far a subject is from completing his task-set reconfiguration on task-switch trials at the time of target onset. With normal controls for instance, the gradually diminishing task-switch costs with increasing CT interval indicate that, as the interval increases, subjects get closer and closer to completing their task-set reconfiguration on task-switch trials at the time when the target is presented. As discussed above, patients PLD and POB apparently fail to perform an advance task-set reconfiguration from the time of task-cue onset. Remarkably though, patient POB showed task-switch costs of a normal magnitude in Exp. 1, thereby suggesting that he is capable of rapidly reconfiguring when the target is presented. This is not so for patient PLD, however. Thus, in addition to his incapacity of advance reconfiguration, this patient also exhibits severely magnified task-switch costs at all CT intervals relative to the neurologically intact controls. This latter feature of PLD's performance in Exp. 1 suggests that he suffers from a dual impairment of executive function. One that prevents the initiation of advance task-set reconfiguration prior to the onset of the target (discussed above), and another that affects his ability in actually performing this reconfiguration even when the imperative stimulus has been presented.

EXPERIMENT 2

Experiment 2 measured task-switch costs as a function of time interval between the subject's response to the previous trial and the presentation of the cue for the next trial (i.e. response-to-cue interval; RCI). The aim of this experiment was to demonstrate that the effect of cue-to-target interval on task-switch costs that was observed in the control groups in Experiment 1 is in fact attributable to task-set reconfiguration and not to proactive interference (see Introduction). If the effect is based on task-set reconfiguration, then it should strictly depend on the time interval between the task-cue and the target (i.e. CTI), and not on the overall time elapsed between the subject's response on a previous trial and the target. In contrast, if the effect is based on proactive interference, then the critical factor should be the total duration separating the response on a particular trial and the target on the next. On its own, Experiment 1 cannot clearly dissociate between these two processes since a change in CTI (with RCI fixed) also implies a change in the interval between response and the next target. By varying RCI while maintaining CTI fixed, Experiment 2 will allow this dissociation.

METHOD

Participants

The subjects who served in Exp. 1 also served in Exp. 2. The order in which the experiments were administered to a particular subject was determined randomly.

Stimuli, materials and procedure

The stimuli and materials used were the same as in Exp. 1. The procedure was the same as well, with the following exceptions: 1- the cue-to-target interval (i.e. CTI) was held constant at 750 msec; 2- the time interval between the subject's response to a target and the task-cue for the next trial (response-cue interval, RCI) was varied (150, 450, 850, 1550 msec).

The dependent variables were response times and error rates. The independent variables were Task-switch (hold vs. switch tasks across consecutive trials), and Response-to-cue interval (RCI : 150, 450, 850, and 1550 msec). Task-switch costs were measured by the performance contrast between the hold and switch conditions at each RCI.

RESULTS

As in Experiment 1, the first trial of each block was not included in data analyses since it was neutral with respect to the task-switch factor. The reaction times

(RTs) associated with errors or with trials in which the subject's answer was not detected for technical problems with the microphone were not considered for data analysis. Outlier RTs were also removed from the data of an individual subject if they were more than three standard deviations away from the subject's mean for that condition. In all these cases, the observation for the following trial was also discarded from the data analyses since it was ambiguous with respect to the Task-switch factor. The percentages of discarded trials of each type are reported for each control group and each TBI subject in Table 3.

INSERT TABLE 3 NEAR HERE

Control groups

Correct RTs are shown in Figs. 6 and 7, respectively, for Control groups 1 and 2. Errors rates are shown in Table 4. Correct RTs and error rates were analyzed separately using ANOVAs comprising the factors of Task-switch (hold vs. switch), and RCI (150, 450, 850, and 1550 msec) as within-group factors.

INSERT FIGS. 6 AND 7 AND TABLE 4 NEAR HERE

The analysis performed on RTs for both groups showed a main effect of Task-switch : group 1 : $F(1,9) = 17.7$, $p < 0.01$; group 2 : $F(1,10) = 40.27$, $p < 0.01$. As shown in Figs. 6 and 7, the Task-switch effect indicates longer RTs for the switch condition than the hold one. No RCI effect was found : group 1 : F(3,27) = 1.31, n.s.; group 2 : F(3,30) = 0.04, n.s. The two-way interaction of Task-switch x RCI was not significant : group: F(3, 27) = 0.89, n.s.; group 2 : F(3,30) = 2.14, n.s.

The analyses performed on error rates showed a main effect of Task-switch in both control groups, which indicated more frequent errors in the switch than the hold condition : group 1 : F(1, 9) = 27, $p < 0.01$; group 2 : F(1, 10)= 16.6, $p < 0.01$. In both control groups, the main effect of RCI : group 1 : F(3, 27) = 0.28, n.s.; group 2 : F(3, 30) = 1.30, n.s. and the Task-switch x RCI interaction : group 1 : F(3, 27) = 1.43, n.s.; group 2 : F(3, 30) =0.64, n.s. were not significant.

Brain damaged subjects

The RTs observed in MB (Fig. 8) showed no main effect of Task-switch : F(1,280) = 0.004, n.s., or of RCI : F(3,280)= 0.39, n.s. and no Task-switch x RCI interaction : F(3,280)= 0.73, n.s. The analysis of her error rates (overall average of 2.8 %) showed no significant effect.

INSERT FIG. 8 NEAR HERE

POB and PLD both showed a main effect of Task-switch on correct RTs (Figs. 9 and 10): marginally significant for POB; F(1, 281) = 3.37, $p = 0.06$; PLD: F(1, 275)= 59, $p < 0.01$, with shorter RTs in the hold than the switch condition. Similarly to their respective control groups, these patients showed no RCI effect :

POB: F(3, 281) = 0.58, n.s.; PLD: F(3, 275) = 1.34, n.s., and no interaction of Task-switch x RCI : POB : F(3, 281) = 1.04, n.s. and PLD : F(3, 275) = 0.41, n.s.

INSERT FIGS. 9 AND 10 NEAR HERE

No significant effect was found in the analysis of error rates for PLD (overall average of 1.92 %). However, POB (overall average of 4.07 %) showed significantly more errors in the hold than in the switch condition : total χ^2 (3)= 5.31, n.s.; task: χ^2 (1)= 6.23; interval : χ^2 (3)= 2.84, n.s., which indicates fewer errors in the hold than the switch condition.

POB showed task-switch costs that are within the range of those shown by his matched controls, none of them exceeding ±1.2 standard deviations away from the normal mean. Notably however, PLD exhibited abnormally large task-switch costs at all RCIs (z-scores of 2.08; 5.15; 2.32; 2.61; $p < 0.05$, respectively for RCIs of, 150, 450, 850 and 1550 msec).

DISCUSSION

The results of Exp. 2 replicate two of the main features of the observations obtained in Exp. 1. Thus, as in Exp. 1, patient MB showed no task-switch cost and patient PLD exhibited a largely magnified task-switch costs relative to his matched controls. The results of Exp. 2 however, show no main effect of the time interval between the subject's response to a particular target and the onset of the task-cue for the following trial (i.e. response-to-cue interval; RCI) and this variable failed to modulate task-switch costs in all of the brain-damaged patients studied as well as in their matched controls. In this respect, the impact of varying the RCI in Exp. 2 was entirely different from that of variations of the cue-to-target interval (CTI) that were performed in Exp. 1. Another noteworthy point in the results of Exp. 2 is that the observations from patient POB were largely uninformative. Indeed, only the task-switch factor had any impact on his performance and the effect of this factor was in opposite directions for RTs and error rates. This renders POB's results in Exp. 2 difficult to interpret, and therefore they will not be discussed any further.

As in the previous experiment, patient MB failed to show the task-switch cost observed in her matched controls. It was argued above that this feature of MB's performance was an indication of her incapacity of maintaining her current task-set in the short time interval separating her response on a particular trial and the task-cue initiating the subsequent trial. MB's results in Exp. 2 are entirely consistent with this interpretation. What is particularly striking in MB's results in the present experiment however, is that the absence of a task-switch cost is evident even at the shortest RCI. Thus, no indication can be found of a residue of the task-set that MB required to adequately perform the task on any given trial within the shortest time interval between a response and the next target that we could test in the present experiments. What this suggests is that the task-set configuration that is obviously necessary for MB to correctly respond to the target dissolves very rapidly after this response is emitted. As noted previously, this observation is consistent with the observation in a subset of patients with frontal damage who have difficulty in remaining focused on the task that must be performed (Benton, 1991; Evankovitch et al, 1990; Mateer & Williams, 1991). MB's results may be considered an extreme example of this.

In contrast to MB, patient PLD exhibited largely magnified task-switch costs relative to her matched controls. This finding completely replicates a similar observation in this patient in Exp. 1. As discussed previously, this result must be interpreted as an indication of an impairment affecting the process involved in task-set reconfiguration in PLD. Specifically, it appears that the time required by PLD to perform this reconfiguration on task-switch trials is much longer than that required by his matched controls.

Another important observation of Exp. 2 is the fact that variations of the RCI had no impact on performance, neither in the neurologically intact participants nor in the brain-damaged patients. Among other things, this means that changes in the RCI have no impact on task-switch costs, a finding previously noted by Beauchemin et al. (2002). One general implication of this fact is that the total time elapsed between the response to a particular target and the onset of the target for the following trial, varied here with changes in RCI, is irrelevant with respect to task-switch costs. This means that task-switch cost are not a function of proactive interference, as previously argued by Allport et al, (1994), but instead can be attributed exclusively to a task-set reconfiguration process that is required on task-switch trials. Another key implication of this result is that, apart from MB, subjects do not appear to spontaneously abandon their current task-set after a response to the target is emitted. Indeed, had this been the case, one would expect a reduction in the magnitude of the task-switch effect with an increase in the RCI. No such reduction was observed here in any patient or matched control group. The standard finding therefore, is that task-switch costs are fully maintained across all durations of RCI. The only exception to this rule, discussed above, is MB who failed to show a task-switch cost at any interval.

GENERAL DISCUSSION

In both experiments, the results from the two normal control groups have shown significant task-switch costs; that is greater RTs/error rates when the task to be performed on a particular trial was different from that on the previous trial. This observation indicates that it is necessary for participants to reconfigure their task-set when consecutive trials involve a change in the task to be performed on the target. It also shows that this reconfiguration takes a measurable amount of time and that it may be subject to error. This replicates the previous findings of Beauchemin et al. (2002) and of Meiran (1996).

Another important observation from normal controls is that task-switch costs are reduced with an increase in the cue-to-target interval (CTI; Exp. 1) whereas they remain constant with variations in the response-to-cue interval (RCI; Exp. 2). The lack of an effect of RCI indicates that task-switch costs are not simply due to proactive interference. Indeed, a proactive interference effect would have predicted a reduction of task-switch costs with an increase in the overall time interval separating the response on a particular trial and the onset of the target for the next trial (Allport et al., 1994). This prediction is not verified here, since the duration of that interval was varied in Exp. 2 by manipulating RCI, and this had no impact on the results. What this latter observation does indicate however, is that the neurologically intact adolescents studied here spontaneously maintained their task set after their response to the target (at least within the range of RCI examined). However, the CTI effect shows that subjects actively reconfigure their task set on task switch trials once they are shown a task cue instructing them that the task to perform on the next target is different from that of the previous trial. Again, these findings from our normal control groups fully replicate those of Beauchemin et al., and of Meiran, who have respectively studied normal adolescents and adults using a similar paradigm.

Each of the TBI patients reported here diverges in his own way from the normal pattern of results discussed above, and these anomalous performances appear to be psychologically significant. These patterns of divergence are discussed in turn below. Importantly however, it should be emphasized that every TBI subject studied here was able to perform the tasks that were asked of them with a very good level of accuracy. This implies that, although each patient presents a particular form of impairment of endogenous control, they were nevertheless able to configure the task-sets required to perform the location and shape tasks and to do so at the appropriate time, i.e. when a response was required of them.

In both experiments, MB failed to show any significant task-switch cost, i.e. her RTs/error rates did not vary as a function of whether the task to perform was the same or different from that on the previous trial. This was true at every CTI (Exp. 1) and RCI (Exp. 2) that we studied here. This result indicates that, in contrast to normal controls, MB fails to spontaneously maintain her task-set after the production of the response so that there is no measurable trace left of it after a 900 msec delay (i.e. shortest interval between a response and the next target in the present experiments).

Another anomalous performance feature, which was present in both POB and PLD is the lack of reduction of task-switch costs with an increase in CTI (Exp. 1). This observation points to an inertia with respect to task-set reconfiguration. Thus, the results from normal controls suggest that they endogenously initiate the reconfiguration of their task-set immediately after the presentation of the task-cue on task-switch trials. The evidence from POB and PLD indicates that they fail to perform this endogenously triggered reconfiguration. Instead, it appears that they initiate the reconfiguration of the new task set that is required on task switch trials only when the target is presented, presumably through the exogenous control exerted by the target, which requires a response.

Finally, in addition to the anomaly just described, PLD also showed magnified task-switch costs relative to the matched controls in both Exps. 1 and 2. Thus, in addition to exhibiting inertia with respect to task-set reconfiguration, this patient also seemed to require a much longer time than normals to perform this required reconfiguration.

The variety of impairments of endogenous control that were documented here seem to map to clinical deficits that are observed with brain-damaged patients diagnosed as suffering from an executive function disorder, which is most often associated with frontal lobe lesions (Benton, 1991; Evankovitch et al, 1990; Mateer & Williams, 1991). For instance, the impairment in maintaining task-set after the production of a response in patient MB is reminiscent of the distractibility and general difficulty to stay on task in some such patients. Similarly, the inertia affecting task-set reconfiguration in POB and PLD, as seen on frontal lobe lesion patients who exhibit a lack of initiative, or passivity, with patients needing strong cues to initiate action. Finally, the impairment affecting the task-set reconfiguration process itself in POB presents some similarity (albeit in a weaker form) with the perseveration symptoms of some patients with frontal lobe damage.

Finally, it should be mentioned that the variety of impairments that was found here in our TBI patients has implications with respect to the normal operation of the system involved in endogenous control. Thus, behavioral deficits following brain damage may be considered as the consequence of damage to some part of the cognitive system which prevents it from operating normally. Accordingly, specific features of the behavioral deficits exhibited by a brain damaged patient should be a function of the particular mechanism affected and of the way in which it is affected. In turn, the identification of this mechanism should inform on the normal organization of the cognitive system studied. Given the present set of findings, this logic suggests that MB has suffered damage to a particular mechanism involved in endogenous control, which has the function of maintaining the individual's task-set. Following the same logic, it may be proposed that the mechanism affected in POB and PLD is one involved in the advance configuration of a task-set; i.e. prior to the presentation of the stimulus on which to act. Finally, an additional mechanism that seems impaired in patient PLD is the task-set configuration process itself, which appears abnormally slow in this patient compared to his matched controls.

CONCLUSION

This paper has reported the investigation of endogenous control in three TBI patients using the task-switch paradigm. The patterns of behavioral deficits observed vary markedly from one patient to another and each appears to map to a psychologically meaningful and theoretically well specified cognitive impairment. Thus, one patient suffered from a deficit in maintaining her task-set during a short temporal interval following the completion of a task. Two others failed at the advance (i.e. prior to the presentation of the target) reconfiguration of their task-set when it must be changed across consecutive trials. Finally one of the latter patients also exhibited an extreme slowness affecting the task-set configuration process itself. These patterns of impairment underline the variability of cognitive outcomes following TBI. They also inform on the normal functional organization of the mechanisms involved in endogenous control.

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TABLES

Table 1

Percentages of each type of discarded trials for the purpose of RTs analyses and correlations between average correct RTs and error rates for each patient and their respective control group in Experiment 1

Group	Error	Tech problems	Outliers	RT-err. Correl.
Control 1	5 %	1.82 %	1.56 %	r(6) = 0.25
Control 2	5.6 %	1.06%	1.26 %	r(6) = 0.35
POB	3.44 %	0.31 %	1.94 %	r(6) = - 0.13
PLD	9 %	4.06 %	4.3 %	r(6) = 0.78
MB	0.6 %	1.25 %	1.9 %	r(6) = - 0.36

Table 2

Error rates (%) for Control groups 1 (11-12 y.o.) and 2 (13-14 y.o.) as a function of task-switch and CTI in Experiment 1

	11-12 y.o. group		**13-14 y.o. group**	
CTI	**Hold**	**Shift**	**Hold**	**Shift**
150	3.4	6.2	3.6	7.1
450	3.4	6.6	3.9	6.6
850	5.5	6.8	5.2	6.6
1550	2.5	6.1	4.3	6.6

Table 3

Percentages of each type of discarded trials for the purpose of RTs analyses and correlations between average correct RTs and error rates for each patient and their respective control group in Experiment 2.

Group	Error	Tech problems	Outliers	RT-err. Correl.
Control 1	7.2 %	1.71 %	2.3 %	r(6) = 0.92
Control 2	6.9 %	0.89 %	1.54 %	r(6) = 0.58
POB	4.07 %	0.3 %	2.29 %	r(6) = -0.32
PLD	1.92 %	2.5 %	4.56 %	r(6) = 0.67
MB	2.8 %	1.8 %	1.34 %	r(6) = - 0.03

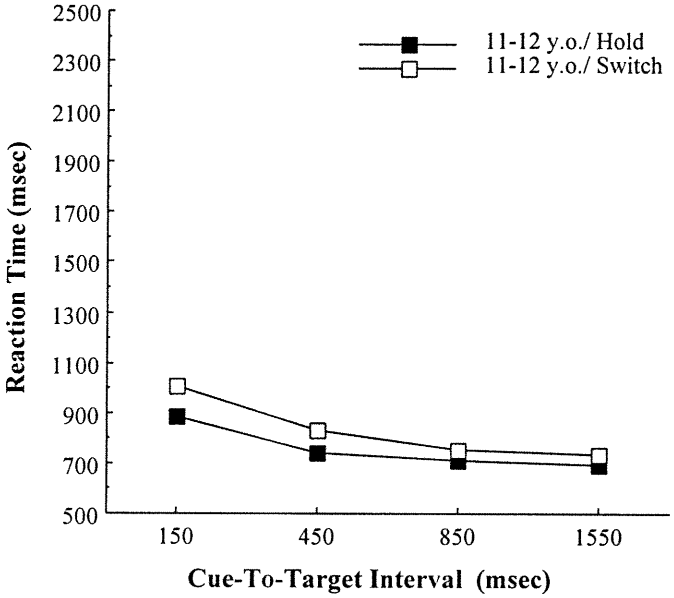
Table 4

Error rates (%) for Control groups 1 (11-12 y.o.) and 2 (13-14 y.o.) as a function of task-switch and RCI in Experiment 2

	11-12 y.o. group		**13-14 y.o. group**	
CTI	**Hold**	**Shift**	**Hold**	**Shift**
150	5.9	8.9	7.3	8.0
450	5.1	10.2	4.5	8.4
850	3.3	10.7	5.5	6.4
1550	2.8	10.3	6.1	9.3

FIGURE CAPTIONS

FIGURES



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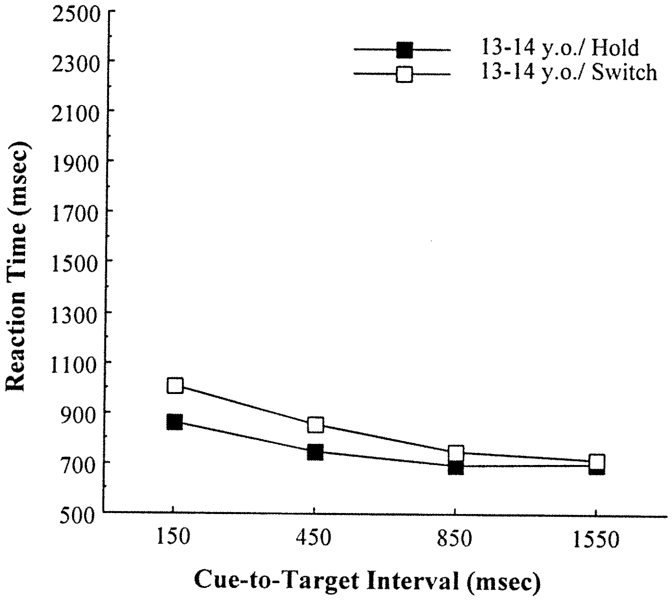

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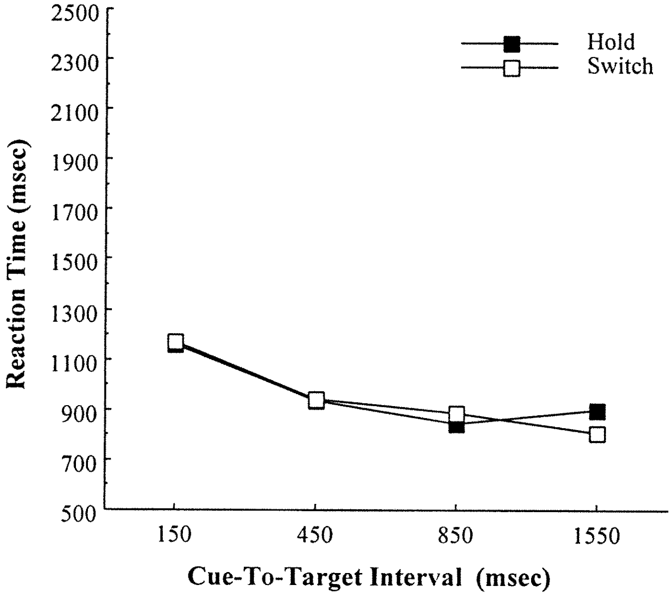

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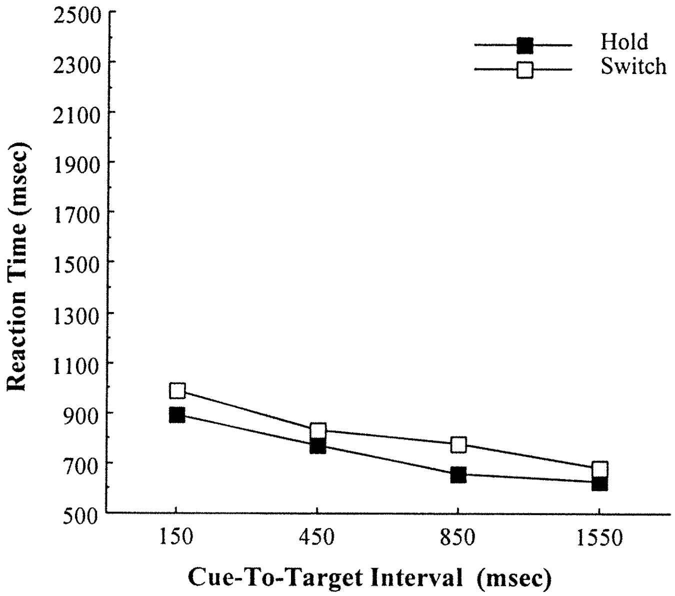

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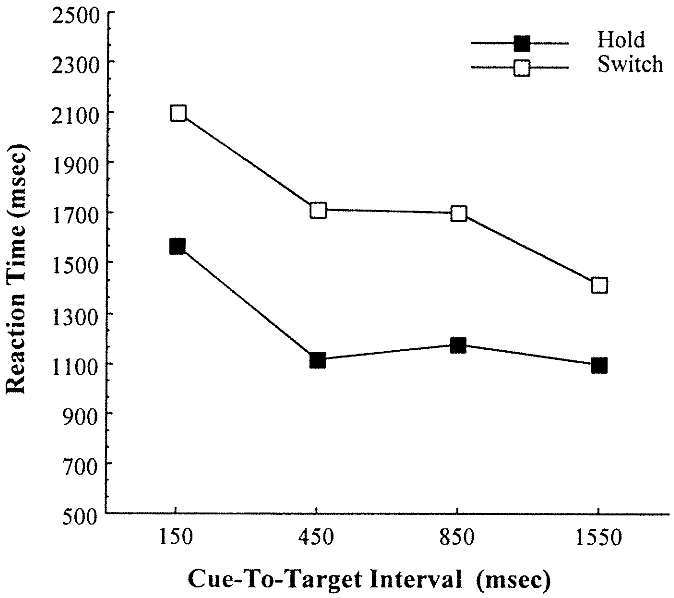

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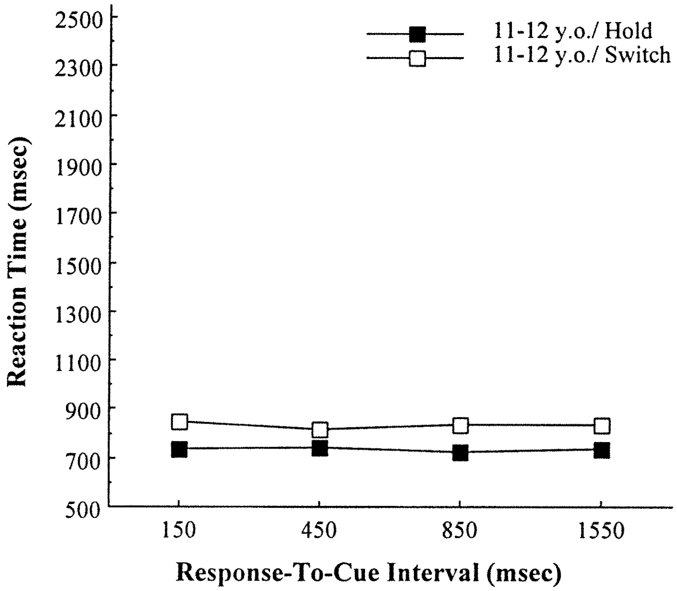

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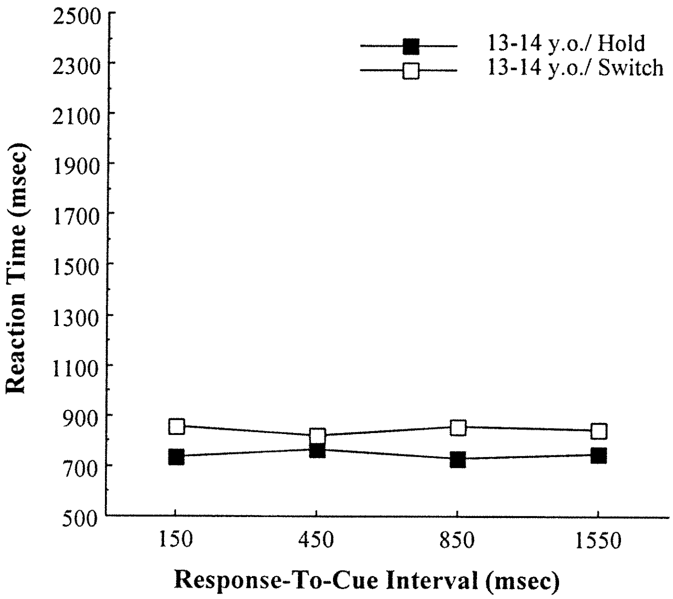

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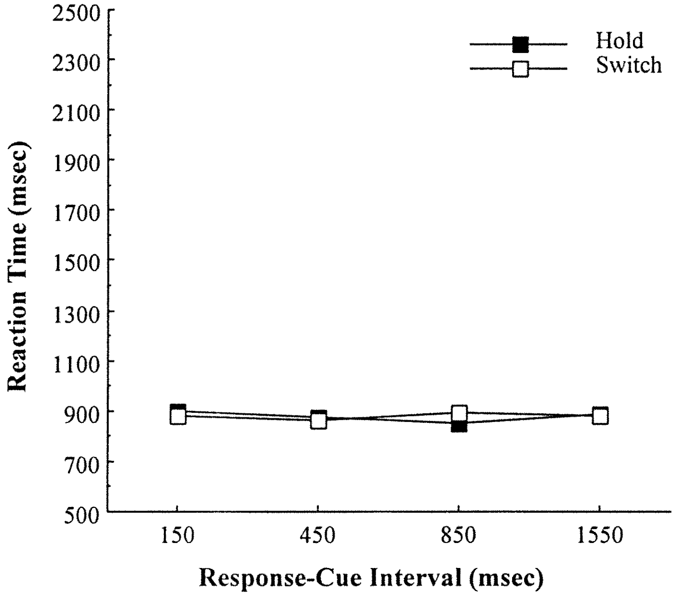

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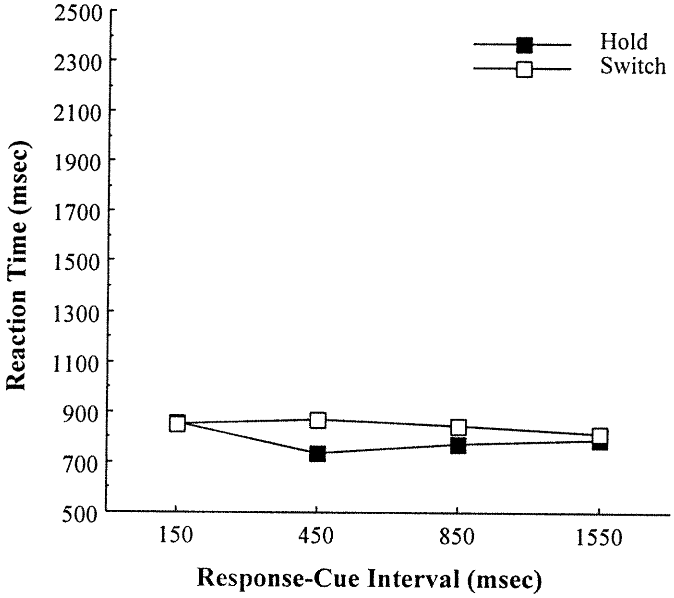

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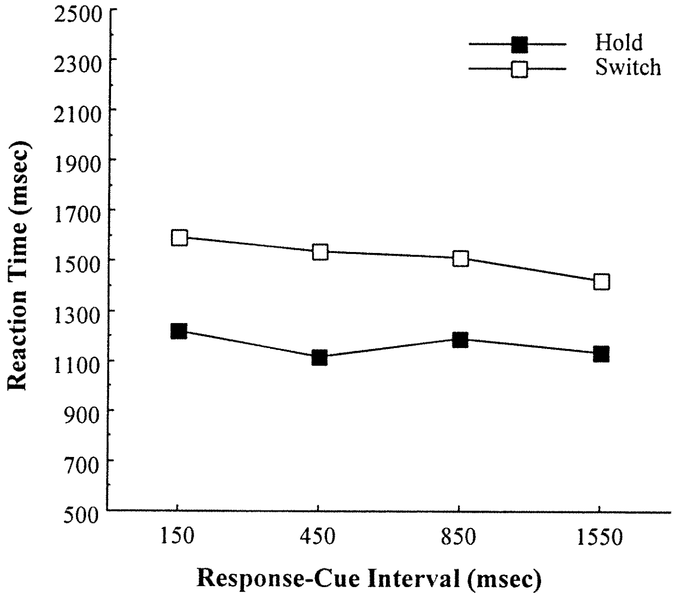

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DISCUSSION GÉNÉRALE

Les travaux présentés dans cette thèse ont porté dans un premier temps sur l'étude du développement du contrôle endogène à l'aide d'un paradigme de changement de tâche auprès d'une population adolescente neurologiquement intacte. Par la suite, nous avons procédé à l'étude des mécanismes liés à ce contrôle auprès d'une population du même âge ayant subi un traumatisme cranio-encéphalique (TCE). Les résultats obtenus contribuent à l'avancement de notre compréhension du développement des aspects volontaires liés au contrôle de tâche et des effets d'un TCE sur les différents mécanismes impliqués. La discussion qui suit traitera tout d'abord de la problématique développementale et des implications à tirer de nos observations. Nous discuterons ensuite de la signification des résultats obtenus dans l'étude du contrôle endogène chez les patients TCE de même que des caractéristiques qu'ils suggèrent au niveau de l'architecture cognitive normale du système de contrôle endogène. Enfin, la présente discussion abordera la question des effets particuliers des lésions cérébrales chez les individus n'ayant pas atteint une pleine maturité et celle de l'évaluation clinique des fonctions exécutives chez les personnes cérébrolésées.

DÉVELOPPEMENT DU CONTRÔLE ENDOGÈNE CHEZ LES ADOLESCENTS

Les résultats rapportés dans le premier article constituant cette thèse montrent une évolution des capacités de reconfiguration du schème comportemental au cours de l'adolescence. Ainsi, notre observation d'un coût de changement de tâche réduit chez les sujets faisant partie du groupe 15-18 ans indique une plus grande efficacité chez ces sujets à reconfigurer leur schème comportemental lors d'essais impliquant un changement de tâche que chez les participants âgés entre 11 et 14 ans.

Nos observations ont également montré un développement des capacités des sujets à maintenir leur disponibilité à répondre aux exigences de l'expérience suite à la production de réponses au cours de l'adolescence. Ainsi, la forme de l'interaction Groupe x IIC observée à l'Expérience 1 du premier article indique que les sujets du groupe 11-14 ans ont une moins bonne capacité que ceux du groupe 15-18 ans à maintenir leur attention sur l'expérience qui leur est administrée pendant le court intervalle temporel séparant leur réponse du début de l'essai suivant.

Enfin, une comparaison entre nos observations de l'Expérience 1 du premier article et celles obtenues précédemment par Rogers et Monsell auprès de participants adultes suggère que l'effet du temps sur le processus de reconfiguration du schème comportemental est qualitativement comparable chez les adolescents et chez l'adulte. Ainsi, les sujets initient dès que possible (ici, au moment de la présentation de l'indice de tâche) la reconfiguration du schème comportemental, et celle-ci se maintient pour une période d'environ 600-850 msec (la relative imprécision de cette estimation est fonction des intervalles temporels qui ont été étudiés jusqu'à maintenant par Rogers et Monsell et par nous-mêmes). Le processus de reconfiguration n'est complété qu'au moment de la présentation de la cible, tel qu'indiqué par un coût de changement de tâches résiduel et stable pour les CTI supérieurs à 850 msec.

Nos observations relatives à l'évolution du contrôle endogène au cours de l'adolescence vont dans le sens des observations neuroanatomiques démontrant que les aires frontales du cerveau, particulièrement impliquées dans les fonctions exécutives, poursuivent leur développement durant la période adolescente. Nos résultats indiquent que certains processus élémentaires liés à la composante intentionnelle du contrôle lors de l'exécution d'une tâche poursuivent leur développement durant cette période. Ils contredisent ainsi les affirmations faites par certains auteurs voulant que le développement des fonctions exécutives soit complété dès l'âge de 12 ans (Appelof et Augustine, 1986; Chelune et Baer, 1986; Kirk et Kelly, 1986).

ATTEINTE DU CONTRÔLE ENDOGÈNE CHEZ LES ADOLESCENTS TCE

Les résultats du deuxième article présenté ici ont non seulement permis de montrer des différences quantitatives mais également des différences qualitatives entre les patients qui ont été évalués et leur groupe contrôle apparié.

Il est à souligner également que la nature des atteintes et les mécanismes impliqués varient à travers les cas examinés. Ainsi, l'un des sujets cérébrolésés examinés (MB) présente une atteinte marquée de sa capacité à maintenir spontanément un schème comportemental suite à l'émission de sa réponse à une cible. Deux autres des patients examinés (PLD et POB) présentent, quant à eux, une incapacité à initier la reconfiguration de leur schème comportemental de façon endogène pendant l'intervalle temporel séparant la présentation de l'indice de tâche et de la cible. Ainsi, contrairement aux sujets normaux, ces patients ne semblent capables d'initier la reconfiguration de leur schème comportemental qu'au moment où la cible est présentée, présumément à partir d'un contrôle exogène. Enfin, l'un de ces deux patients (PLD) présente également une lenteur anormale au niveau du processus de reconfiguration du schème comportemental comme tel, ce qui se manifeste par un coût de changement de tâches anormalement élevé.

Les atteintes documentées ici auprès de nos patients TCE semblent apparentées à certains troubles comportementaux qui ont déjà été documentés chez des patients avec des lésions frontales (Benton, 1991; Mateer & Williams, 1991; Evankovitch et al, 1990). Ainsi, la difficulté de la patiente MB à maintenir son schème comportemental rappelle la distractibilité rencontrée chez des patients avec des lésions frontales. Par ailleurs, le trouble d'initiation endogène du processus de reconfiguration du schème comportemental rencontré chez PLD et POB ressemble, du moins pour certains aspects, à l'inertie qui peut être rencontrée occasionnellement dans le contexte de lésions antérieures. Finalement, la lenteur du processus de reconfiguration mise en évidence chez le patient PLD ressemble à la rigidité mentale souvent rencontrée lors de lésions des lobes frontaux.

Il est à souligner que l'observation d'atteintes fonctionnelles spécifiques, chez les patients TCE fournit des indications pertinentes quant à l'organisation du système de contrôle endogène chez l'individu normal. En effet, la nature des déficits rencontrés chez les sujets cérébrolésés rapportés dans le deuxième article suggère que le contrôle endogène du comportement implique au moins trois mécanismes distincts : 1- maintien spontané du schème comportemental suite à l'émission d'une réponse ; 2- initiation endogène de la reconfiguration du schème comportemental (i.e. avant la cible); 3- processus de reconfiguration du schème comportemental lui-même.

Les observations rapportées dans le deuxième article indiquent que le paradigme de changement de tâches peut s'avérer un outil puissant pour l'évaluation objective et quantitative d'atteintes du contrôle endogène chez des patients cérébrolésés de même que pour une caractérisation des mécanismes. Il est à souligner également que l'utilisation du paradigme de changement de tâches a permis de contribuer à une opérationalisation du modèle du système de supervision attentionnelle de Norman et Shallice (1986). Ainsi, notre étude de patients TCE a permis la démonstration inédite de trois processus élémentaires impliqués dans le contrôle endogène et leur association à certains paramètres des performances observées.

LÉSIONS AFFECTANT LE CERVEAU EN DÉVELOPPEMENT

Les résultats portant sur le développement normal du contrôle endogène rapportés dans le premier article indiquent que le développement du contrôle endogène de nos sujets cérébrolésés n'était pas complet au moment où ils ont subi leur TCE. Malgré l'immaturité de leur système cognitif, les patients cérébrolésés étudiés ici présentent des déficits qui peuvent être assimilables à des observations cliniques faites auprès d'individus adultes ayant subi des lésions frontales focales. De plus, les déficits rencontrés chez nos patients TCE correspondent à des atteintes très spécifiques et non pas à des troubles indifférenciés. Ces caractéristiques suggèrent que les atteintes du contrôle endogène rencontrées ici ne sont probablement pas très différentes de celles que nous pourrions avoir rencontré auprès d'une population de cérébrolésés adultes.

Une explication possible de cette observation est que les mécanismes de contrôle endogène étaient en place au moment où les patients ont subi leur lésion et que la poursuite du développement qui restait à faire consistait simplement en une optimisation de ces mécanismes. Si tel est le cas, des sujets ayant subi une lésion à un âge plus jeune alors que les mécanismes de contrôle endogène ne sont pas bien en place ou bien différenciés, auront des déficits différents de ceux rapportés ici. En particulier, on peut s'attendre à ce que ces déficits soient difficiles à comparer avec les atteintes qui peuvent être rencontrées dans une population cérébrolésée adulte et qu'ils soient également moins spécifiques (ou plus globaux) que ceux observés dans la présente étude.

Il est évident toutefois que même si les données actuelles permettent certaines spéculations quant à l'effet des lésions affectant le cerveau immature, elles ne suffisent pas pour proposer ces hypothèses. Idéalement, une étude cherchant à répondre à cette question devrait couvrir un spectre d'âge plus étendu et inclure des sujets ayant subi leur lésion au moment où les mécanismes de contrôle endogène étaient encore plus immatures. De plus, il est probable qu'un suivi longitudinal de l'évolution des atteintes après la lésion puisse également contribuer à offrir un portrait plus clair et plus complexe des effets du développement normal ou déficitaire sur le contrôle endogène.

ÉVALUATION CLINIQUE DES FONCTIONS ENDOGÈNES

Les épreuves exécutives utilisées en clinique font appel à des comportements souvent complexes et la correspondance entre la performance mesurée et les mécanismes psychologiques ciblés n'est pas toujours transparente, celle-ci exigeant souvent une analyse de type qualitatif.

En revanche, dans le paradigme de changement de tâche utilisé dans les études rapportées ici, il y a une proximité conceptuelle entre les mécanismes psychologiques ciblés et la mesure obtenue. De plus, les exigences que le contexte expérimental impose au sujet sont relativement simples. Dans ces conditions, nos résultats montrent des altérations chez les patients cérébrolésés qui sont signalées par des différences de performance très marquées comparées à celle de sujets neurologiquement intacts. De plus, le paradigme permet de mettre en relation les déficits observés et des mécanismes élémentaires du contrôle endogène. Pour ces raisons, le paradigme expérimental utilisé ici semble nettement avantageux en comparaison aux tâches cliniques utilisées habituellement pour l'évaluation des fonctions exécutives.

Il est à noter que l'essentiel des informations relatives aux atteintes du contrôle endogène chez les patients étudiés dans le deuxième article repose sur la seule expérience où nous avons fait varier l'intervalle temporel séparant la présentation de l'indice de tâche et de la cible. L'administration de cette expérience n'exige que très peu de temps (environ vingt minutes). De plus, en convertissant la modalité de réponse verbale en réponse motrice, il deviendrait alors possible d'évaluer des patients avec atteintes verbales sévères.

Quant à l'expérience impliquant une variation de l'intervalle temporel entre la production de la réponse à un essai et la présentation de l'indice de tâche pour l'essai suivant, sa fonction dans les études rapportées ici en était principalement une de contrôle. En effet, cette expérience avait comme but de vérifier que les coûts de changement de tâche observés étaient le reflet d'un processus endogène de reconfiguration du schème comportemental plutôt que d'un ajustement rétroactif, ce que nous avons démontré. Dans un contexte clinique visant une évaluation du contrôle endogène, il semble que ce type de contrôle expérimental ne présente qu'une utilité limitée et donc qu'une évaluation de l'effet de l'intervalle réponse-indice de s'avère pas particulièrement nécessaire.

Ces éléments appuient l'intérêt potentiel du paradigme de changement de tâches dans le contexte de l'évaluation clinique de patients cérébrolésés. Il semble que ce potentiel mériterait d'être exploré par des études portant sur des populations cérébrolésées, d'âges et d'étiologies variables (notamment l'étude des patients avec des atteintes frontales ou souffrant de démences apparaît particulièrement pertinente).

CONCLUSIONS

L'étude du développement du contrôle endogène chez les adolescents de même que l'étude des atteintes pouvant affecter cette fonction chez des jeunes TCE ont offert les démonstrations suivantes: 1- l'occurrence d'un développement quantitatif des mécanismes de contrôle endogène pendant l'adolescence, suggérant que ces mécanismes sont déjà en place au début de l'adolescence et que ceux-ci évoluent en efficacité jusqu'à l'âge adulte ; 2- des atteintes marquées des mécanismes impliqués dans le contrôle endogène chez des adolescents TCE, dont les propriétés varient de façon qualitative à travers les cas ; 3- l'existence de trois processus distincts impliqués dans le contrôle endogène chez l'individu normal, soit le maintien spontané du schème comportemental en cours suite à l'émission d'une réponse, l'initiation endogène de cette reconfiguration et la reconfiguration du schème comportemental ; 4- l'utilité potentielle du paradigme de changement de tâches en tant qu'outil d'évaluation clinique des fonctions exécutives, représentant une opérationalisation du SSA de Norman et Shallice (1986).

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