Université de Montréal

# Représentations égocentrique et allocentrique d'une cible mémorisée lors d'un mouvement de pointage chez le jeune adulte et la personnes âgée

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Représentations égocentrique et allocentrique d'une cible mémorisée
lors d'un mouvement de pointage chez le jeune adulte et la personnes âgée

présentée par :

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a été évaluée par un jury composé des personnes suivantes :

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| François Prince ................................ | représentant du doyen |

Thèse acceptée le : ...............

# SOMMAIRE

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L'atteinte d'une cible qui n'est plus visible nécessite qu'elle soit maintenue en mémoire. Le but de la présente thèse était de déterminer les facteurs susceptibles d'améliorer ou de détériorer la représentation de la cible en mémoire et d'évaluer leur impact sur la performance de pointage. Ces facteurs sont : le temps de présentation visuelle de la cible, le délai de rappel, la présence ou non d'un contexte visuelle pendant la présentation de la cible et le rappel, l'augmentation du temps de mouvement (ou l'effet de distance) et l'âge des participants. Afin de déterminer l'influence de ces facteurs, une seule cible temps était présentée (sauf pour l'étude 4, où quatre cibles étaient présentées) à des jeunes adultes et des personnes âgées pendant une courte période de temps (entre 50 ms et 1000 ms). Par la suite, la cible disparaissait et les participants devaient attendre (entre 0 et 10000 ms) un signal sonore avant d'amorcer leur mouvement. Le mouvement n'était pas habituellement pas contraint (sauf pour l'étude 2, expérience 1 où les participants devaient atteindre les cibles rapprochées dans un temps de mouvement variant entre 2 et 5 secondes et les cibles éloignées dans un temps de mouvement inférieur à une seconde). La cible était présentée soit seule ou avec un contexte visuel l'entourant. Pour les trois premières études, le mouvement de la main (ou du curseur) se dirigeant vers la cible n'était pas visibles. Pour l'étude 4, les participants pouvaient voir le déplacement d'un curseur à l'écran pendant le déplacement de leur main. L'étude 1 a démontré que le temps de présentation ne permet pas un meilleur encodage et maintien de l'information en mémoire. Toutefois, la présence d'un délai de rappel de moins de une seconde entre la présentation de la cible et l'amorce du mouvement permet de diminuer la variabilité du mouvement de pointage. Tel serait le cas puisque la cible (et possiblement

le contexte qui l'entoure) est maintenue en mémoire iconique. L'étude 2 a démontré que la représentation de la cible se détériore lorsque le temps de mouvement nécessaire à l'atteinte d'une cible augmente. L'étude 3 a pour sa part démontrer que la présence d'un contexte pendant la présentation de la cible modifiait la planification du mouvement de pointage. Toutefois, le contexte visuel ne permet pas de maintenir plus efficacement l'information, du moins dans le cas d'un délai de rappel de 100 ms. Pour les trois premières études, aucune différence importante n'a été observé entre les jeunes adultes et les personnes âgées. Sur la base de ces résultats, nous avons argumenté que lors de l'exécution d'un mouvement de pointage effectué vers une seule cible maintenue en mémoire alors que le déplacement de la main n'est pas visible, la cible serait encodée dans un cadre de référence égocentrique, c'est-à-dire en fonction du corps. Lors de l'étude 4, nous avons évalué le mouvement de pointage de jeunes adultes et de personnes âgées dans une situation où la cible est maintenue dans un cadre de référence allocentrique. Les cibles sont alors encodées en fonction d'éléments externes au corps. Les résultats de cette étude ont indiqué que l'atteinte d'une cible maintenue dans un tel contexte étaient plus variable chez les personnes âgées que chez les jeunes adultes. Cette dernière étude démontre que dans le cadre d'un mouvement de pointage, une cible peut être maintenue sous différentes formes et ainsi être affecté différemment par les manipulations expérimentales.

# RÉSUMÉ

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Cent trente et un participants ont pris part à quatre études afin d'éclaircir le rôle de la mémoire lors de l'exécution d'un mouvement de pointage. Il a été démontré à plusieurs reprises que le mouvement de pointage vers une cible qui n'est plus visible est moins précis que le mouvement de pointage vers une cible qui est toujours visible. Dans le cadre de la présente thèse, différents facteurs pouvant expliquer cette différence ont été étudiés. L'emphase a été mise sur l'étude de facteurs susceptibles d'influencer la mémorisation de la cible (et du contexte entourant cette cible) et l'impact de ces facteurs sur la qualité du mouvement de pointage. De façon secondaire, la performance des personnes âgées a également été étudiée afin de déterminer si le maintien de la position d'une cible en mémoire est affecté avec l'âge.

Lors de la première étude, deux expériences ont été effectuées afin d'évaluer l'influence du temps de présentation de la cible de même que du délai de rappel sur la mémorisation d'une cible. Une cible était présentée visuellement aux participants pendant 50 ms ou 500 ms. Le mouvement de pointage était amorcé après un délai de 0, 100, 1000 et 10000 ms. L'hypothèse était que l'augmentation du temps de présentation permettrait un encodage et un maintien plus efficace de la position de la cible, ce qui devrait se refléter par une diminution de l'erreur de pointage habituellement observée lors de l'augmentation du délai de rappel. Les résultats n'ont pas confirmé cette hypothèse. Toutefois, il a été observé que le temps de présentation le plus longs de même que les trois délais de rappel les plus courts résultent en un mouvement de pointage plus variable que le temps de présentation le plus court et le délai de rappel le plus long. En ce sens, l'étude 1 révèle la persistance d'une représentation visuelle de la cible en mémoire

iconique, laquelle permet de réduire la variabilité du mouvement de pointage. En raison de la durée très courte de cette représentation (moins d'une seconde), il est nécessaire d'augmenter la vitesse de pointage. L'âge des participants n'affecte pas la performance de pointage.

Lors de la deuxième étude, nous avons évalué un autre facteur susceptible d'affecter la mémorisation de l'information, soit l'augmentation du temps de mouvement nécessaire à l'atteinte d'une cible. Il a été noté que l'erreur de pointage et particulièrement la variabilité de ce mouvement augmente en fonction de la distance de la cible par rapport à la base de départ, c'est ce qu'on appelle l'effet de distance. Pour la première expérience, la moitié des participants devait atteindre les cibles rapprochées de la base de départ dans un temps de mouvement plus long que les cibles éloignées. L'autre moitié des participants a effectué le mouvement de pointage sans contrainte de temps. L'amorce du mouvement de pointage s'effectuait après un délai de rappel de 100 ms ou 10000 ms. Un effet de distance a été obtenu pour le groupe ayant effectué le mouvement de pointage sans contrainte de temps. Toutefois, le groupe ayant atteint les cibles rapprochées dans un temps de mouvement plus long que les cibles éloignées ont démontré un effet de distance inversé, c'est-à-dire que l'atteinte des cibles rapprochées était plus variable que l'atteinte des cibles éloignées. Lors de la deuxième expérience, nous avons démontré que l'effet de distance ne prend pas place lorsque la cible est visible. Il a été proposé que le mouvement interfère avec la représentation mnésique de la cible. Une augmentation du temps de mouvement nécessaire à l'atteinte d'une cible éloignée résulterait donc en une augmentation de l'interférence. L'effet de distance n'est pas modulé par l'âge des participants.

Le but de la troisième étude de la présente thèse était de déterminer si le maintien d'une cible en vue de son atteinte était facilité par la présence d'un contexte visuel lors de la présentation de la cible. Les participants devaient pointer vers une cible visible ou non qui avait été présentée avec ou sans contexte. Pour la moitié des essais, le contexte restait présent lors de l'exécution du mouvement. Les résultats indiquent que le contexte visuel biaise le processus de planification du mouvement, mais non le contrôle du mouvement, et ce, que la cible et le contexte soient visibles ou non. Toutefois, la variabilité du mouvement de pointage est similaire avec ou sans contexte, ce qui indique que le contexte ne permet pas un maintien plus adéquat de la position de la cible en mémoire. Les participants âgés utilisent l'information du contexte de façon similaire aux jeunes adultes pour planifier le mouvement de pointage.

Lors des trois premières études, il a été démontré que les personnes âgées sont en mesure de maintenir la position d'une seule cible de façon aussi efficace que les jeunes adultes. Il a été proposé que le maintien de l'information lors des trois premières études s'effectuait dans un cadre de référence égocentrique. Or, le maintien de l'information dans un tel cadre ne serait pas affecté avec l'âge. Toutefois, Desrocher et Smith (1998) ont suggéré que le maintien de l'information allocentrique serait déficitaire avec le vieillissement. Pour la quatrième étude de la présente thèse, nous avons vérifié cette dernière hypothèse dans le contexte d'un mouvement de pointage. Pour ce faire, quatre cibles étaient présentées aux participants. Après un délai de rappel, trois des quatre cibles étaient présentées à nouveau selon la même configuration, mais à un endroit différent de leur position initiale. Étant donné que les participants ignoraient à quel endroit seraient présentées les cibles, ils n'avaient pas le choix de les encoder dans un cadre allocentrique. Les résultats ont démontré que l'atteinte de la cible manquante était beaucoup plus variable chez les personnes âgées que chez les jeunes adultes. Le maintien de l'information allocentrique serait donc effectivement affecté avec l'âge.

Les quatre études présentées dans la cadre de la présente thèse avaient pour but de déterminer les facteurs susceptibles de modifier l'intégrité de la représentation mnésique. Un seul facteur a été identifié, de façon indirecte, comme améliorant le maintien en mémoire de la position de la cible, soit la présence d'un délai de rappel court (moins d'une seconde). Par contre, deux facteurs ont été désignés comme affectant l'intégrité de la représentation mnésique, soit l'augmentation du délai de rappel et l'effet de distance (ou l'augmentation du temps de mouvement). L'âge des participants, le temps de présentation de la cible et la présence ou non d'un contexte n'affectent pas la qualité de la représentation mnésique de la cible lorsque celle-ci est maintenue dans un cadre de référence égocentrique. Toutefois, nous avons démontré que le maintien d'une cible dans un cadre de référence allocentrique est affecté avec l'âge.

La présente thèse a donc permis d'évaluer l'impact de différents facteurs susceptibles d'influencer la représentation mnésique de la cible. Ces facteurs ont été évalués principalement dans des conditions où l'information est maintenue dans un cadre de référence égocentrique. Il serait intéressant dans le futur d'évaluer l'impact de ces facteurs sur une représentation allocentrique de la cible.

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# CHAPITRE 1

# REVUE DE LA LITTÉRATURE

# INTRODUCTION GÉNÉRALE

La réalisation d'un mouvement de pointage alors que la cible à atteindre et la main se déplaçant vers cette cible sont visibles résulte en une erreur de pointage minime, du moins lorsque le temps de mouvement est relativement long. Tel est le cas parce qu'il est alors possible de comparer en tout temps l'écart séparant la main (ou l'objet servant à pointer) de la cible à atteindre. Cette conclusion s'applique autant pour les jeunes adultes que pour les personnes âgées (Chaput & Proteau, 1996).

Toutefois, il arrive que la main qui se déplace vers la cible, le contexte visuel entourant la cible, ou bien la cible elle-même ne soit pas visible lors du mouvement de pointage. Le retrait de ces informations visuelles entraîne des modifications importantes au niveau de la planification, du contrôle, et bien évidemment du résultat même du mouvement de pointage (voir Desmurget, Pélisson, Rossetti, & Prablanc, 1998 pour une revue). Dans cette situation, peu importe la source d'information alors absente, celle-ci doit être maintenue en mémoire. La présente thèse a pour but de déterminer l'impact du retrait de la vision de la main, du contexte visuel et de la cible sur la précision d'un mouvement de pointage, et surtout le rôle de la mémoire lorsque le mouvement doit être réalisé dans une telle situation. Dans les pages qui suivent, l'impact du retrait de la vision de la main sur la précision du mouvement de pointage sera d'abord discuté. Par la suite, l'impact du retrait de la vision de la cible sera abordé, spécifiquement en fonction du rôle de la mémoire dans cette situation. Ces thèmes seront traités toujours en prenant soin de déterminer, dans l'ordre, l'impact du contexte visuel et du vieillissement sur la performance de pointage.

# REVUE DE LA LITTÉRATURE

## Impact du retrait de la vision de la main pendant le pointage

La vision de la main en déplacement vers la cible convoitée est de première importance pour minimiser les erreurs de pointage. Lorsque l'atteinte de la cible doit être réalisée alors que l'individu peut voir la réalisation de son geste, sa main est, tout comme la position de la cible, codée dans un cadre de référence extrinsèque, c'est-à-dire sans égard à la position du corps. L'information visuelle est alors prédominante pour la planification et le contrôle du mouvement. Il en découle une précision optimale du geste de pointage (Desmurget, Rossetti, Prablanc, Stelmach, & Jeannerod, 1995 ; Elliott, Carson, Goodman, & Chua, 1991, voir Proteau, 1992 pour une revue). Dans ce contexte, tel que proposé par Berkinblit, Fookson, Smetanin, Adamovich, & Poizner, (1995, p.329), « le signal proprioceptif provenant du bras n'est d'aucune utilité » (traduction libre) puisque les participants peuvent comparer directement la représentation visuelle de la cible à la position de la main. Toutefois, on observe une augmentation de l'erreur de pointage lorsque la vision de la main est retirée avant ou pendant l'exécution du mouvement par rapport à une situation où la vision de la main est toujours disponible (Ghilardi, Gordon, & Ghez, 1995; Proteau & Carnahan, 2000, Soechting & Flanders, 1989a, b; Vindras & Viviani, 1998). Afin de bien comprendre la source de cette erreur, il importe de connaître les différentes étapes nécessaires à la planification du mouvement de pointage, soit la localisation de la cible et la transformation de l'information.

### Localisation de la cible

Dans un premier temps, la cible à atteindre doit être localisée dans l'environnement de l'individu. Dans un contexte où plusieurs cibles sont susceptibles d'être présentées, la présentation d'une cible particulière attire en premier lieu l'attention de l'individu (Adam, Paas, Ekering, & van Loon, 1993 ; Adam, Ketelaars, Kingma, & Hoek, 1995). L'individu relâche son attention du point de fixation initial, redirige son attention vers la cible et ancre son attention sur celle-ci. Par la suite, afin de préciser la localisation de la cible, l'individu réalise une saccade visuelle vers celle-ci, ce qui lui permet de la fovéaliser. Cette dernière étape est importante puisque la périphérie de l'œil possède une acuité plus faible que la fovéa (Weitheimer, 1982). La cible est alors codée sous la forme d'une représentation dite « rétinotopique ». Cette représentation combine l'information rétinienne et l'information extra-rétinienne provenant de la position de l'œil dans son orbite (Prablanc, Pélisson, & Goodale, 1986).

### Contexte visuel

Il importe de noter que la présence d'un contexte visuel entourant la cible modifie sensiblement la perception de la position de la cible. Ce contexte visuel est constitué de tous les éléments de la salle d'expérimentation tel que les murs, le mobilier mais également les éléments ajoutés autour de la cible à atteindre. Un contexte visuel riche entraînerait une modification du processus de fovéation de la cible susceptible de modifier la perception de la position de la cible (Conti & Beaubaton, 1980 ; Gnadt, Bracewell, & Andersen, 1991 ; Velay & Beaubaton, 1986).

Selon Coello et Magne (2000), la présence d'un contexte visuel riche favoriserait une meilleure estimation de la distance séparant la base de départ et la cible. En effet, les auteurs ont remarqué que lorsqu'une cible est présentée sans contexte visuel, l'exécution d'un mouvement de pointage effectué sans la vision de la main en déplacement arrivait toujours à court de la cible. L'ajout d'un contexte composé de ronds noirs disposés entre la base de départ et la cible permettait de diminuer ces sous-estimations de la réponse de pointage. De plus, les auteurs ont remarqué que plus le nombre de ronds était élevé, moins la position de la cible était sous-estimée. Toutefois, ces ronds devaient absolument être situés entre la base de départ et la cible pour créer un impact significatif sur l'estimation de la distance à parcourir. L'idée voulant que le contexte favorise une meilleure estimation de la distance de la cible reçoit le support de d'autres auteurs (Conti & Beaubaton, 1980 ; Velay & Beaubaton, 1986).

À l'opposé, le contexte visuel peut nuire à la perception de la position exacte d'une cible. Tel est le cas lorsqu'une illusion prend place. Il a été démontré que des illusions tels les cercles de Tichener (Pavani, Boscagli, Benvenuti, Rabuffetti, & Farnè, 1999 ; van Donkelaar, 1999) ou l'illusion de Müller-Lyer (Binsted & Elliott, 1999) modifient le mouvement de pointage. De plus, des lignes présentes entre le point de fixation et la cible peuvent agir comme source d'interférence et augmenter le temps de localisation de la cible, ce qui fait en sorte que la cible semble plus loin qu'elle ne l'est en réalité (Toni, Gentilucci, Jeannerod, & Decety, 1996).

Vieillissement

Par ailleurs, plusieurs problèmes visuels pouvant affecter la perception de la position d'une cible apparaissent avec l'âge tel que la dégénérescence maculaire liée à l'âge (DMLA), la cataracte sénile, le glaucome et les pathologies rétiniennes. Il importe donc de s'assurer que les personnes âgés participant à des études de pointage n'ont pas de troubles visuels outre ceux corrigés par des lentilles cornéennes. Cette précaution a été prise dans le cadre de la présente thèse. Les problèmes des personnes âgées concernant la localisation d'une cible ont surtout été observés pour des situations où la cible n'est présentée que pendant un bref instant avant l'amorce du mouvement. Cette situation sera abordée subséquemment.

## Transformation de l'information

La réalisation d'un mouvement de pointage alors que la main n'est plus visible nécessite que l'on transfère l'information rétinotopique concernant la cible à l'intérieur d'un cadre de référence commun à la position de la main devant pointer vers cette cible. La façon par laquelle cette dernière opération s'effectue a fait l'objet de nombreuses études et soulevée plusieurs hypothèses. L'une d'elles reçoit l'assentiment de plusieurs auteurs et veut que la cible soit codée dans un cadre égocentrique, c'est-à-dire par rapport au corps, par une transformation successive de sa position (Carrozzo, McIntyre, Zago, & Lacquaniti, 1999 ; Soechting & Flanders, 1989a, b). La représentation rétinotopique évoluerait donc vers une représentation de la cible centrée sur une partie du corps. À cet égard, l'information extra-rétinienne provenant de la représentation rétinotopique facilite ce transfert d'une représentation extrinsèque en une représentation intrinsèque (ou égocentrique) puisque cette information est de même nature que la représentation égocentrique (Desmurget et al., 1998).

Plusieurs auteurs ont tenté de déterminer la partie du corps utilisée pour localiser la position de la cible. Les protocoles expérimentaux de même que les techniques utilisées pour déterminer cette partie du corps sont variés, ce qui a mené à des propositions tout aussi variées. Soechting et Flanders (1989a, b ; Flanders, Helms-Tillery, & Soechting, 1992) ont réalisé une expérience pour laquelle les participants devaient pointer vers diverses cibles dans un espace tridimensionnel. Lors de la condition standard utilisée par les auteurs, le mouvement d'atteinte était réalisé alors que la cible n'était plus visible. Le mouvement était également effectué sans la vision de la main se dirigeant vers la cible. Les mouvements réalisés vers les cibles éloignées s'arrêtaient à court de la cible (jusqu'à 10 cm d'erreur). L'erreur directionnelle était cependant très faible. Les auteurs ont proposé que la position de la cible était déterminée en fonction de coordonnées sphériques centrées autour de l'épaule (voir aussi Caminiti, Johnson, & Urbano, 1990). De cette façon, un vecteur que l'on pourrait qualifier de « proprioceptif » s'établit entre l'orientation angulaire initiale des articulations du bras et de l'avant bras et l'orientation que devrait avoir le bras et l'avant bras à la fin du mouvement. Ainsi, la représentation égocentrique (dite « intrinsèque » par les auteurs parce qu'elle réfère à la disposition des éléments du corps entre eux) du bras et de l'avant-bras est comparée à la position de la cible par rapport à l'épaule (représentation égocentrique mais dite « extrinsèque » par les auteurs parce qu'elle réfère à des éléments externes au corps). Le plan moteur a donc pour but de joindre ces deux représentations.

Selon ces auteurs, l'erreur de pointage lorsque la main n'est pas visible provient de la transformation inadéquate (parce que linéaire) de la position extrinsèque de la cible en une position intrinsèque et non d'une mauvaise localisation visuelle de la cible, d'une mémorisation inadéquate ou d'une erreur d'exécution du mouvement de pointage (Helms-Tillery, Flanders, & Soechting, 1991 ; Flanders et al., 1992 ; Soechting & Flanders, 1989a, b, voir Berkinblit et al., 1995 ; Darling & Miller, 1993 pour des propositions similaires). À cet égard, les erreurs de transformations peuvent être réduites en présentant la cible directement dans un cadre égocentrique. Pour ce faire, l'expérimentateur déplace la main du participant vers la cible sans que celui-ci n'ait accès à aucune représentation visuelle de la cible. Les positions de la cible et de la main sont donc encodées dans un cadre commun, soit un cadre égocentrique. Étant donné qu'aucune transformation n'est nécessaire dans ce type de tâche, l'erreur est inférieure par rapport à une situation où la cible est localisée visuellement (Soechting & Flanders, 1989a, b).

Certains auteurs proposent que la cible serait plutôt codée en fonction de la position initiale de la main ou du bras (Carozzo et al., 1999 ; Chieffi, Allport, & Woodin, 1999 ; Flanders et al., 1992 ; Gordon, Ghilardi, & Ghez, 1994 ; Meegan & Tipper, 1998 ; Rossetti, Desmurget, & Prablanc, 1995 ; Vindras & Viviani, 1998). Cette proposition est souvent associée à l'idée voulant que le mouvement est programmé à l'aide d'un vecteur (voir Desmurget et al., 1998 pour une revue de l'approche vectorielle).[1] Lors de la réalisation d'un mouvement de pointage, les participants comparent d'abord la position initiale de la main (origine du vecteur) et la position attendue de la main à la fin du mouvement (position de la cible et fin du vecteur) et programment ensuite le mouvement (en amplitude et en direction) afin de joindre les deux bouts du vecteur.

Afin de déterminer l'origine du vecteur, les auteurs analysent habituellement la répartition de l'erreur variable des réponses d'un même participant (Gordon et al., 1994 ; McIntyre, Stratta, & Lacquaniti, 1997 ; Messier & Kalaska, 1997, 1999). L'erreur variable représente la dispersion des réponses autour de la moyenne (Schmidt & Lee, 1999). Cette technique a été utilisée entre autre par Carrozzo et al. (1999). L'intérêt de cette dernière étude provient du fait que les auteurs ont comparé l'atteinte d'une cible visible alors que la main était visible ou non. Dans la condition où la main était visible,

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[1] Cette approche explique mieux la précision des mouvements de pointage, notamment ceux effectués à partir de positions de départ diverses que d'autres approches de planification du mouvement telle l'hypothèse de contrôle de la position finale (Bizzi Hogan, Mussa-Ivaldi, & Gitzter, 1992).

l'axe de variabilité maximale convergeait vers un point situé entre les deux yeux. Les auteurs ont donc proposé que la cible serait codée dans un cadre de référence centré sur les yeux (viewer-centered). Toutefois, lorsque la main n'est pas visible, cette représentation évoluerait vers une représentation centrée sur le bras.

L'erreur constante (appelée parfois erreur systématique) qui représente la déviation moyenne du mouvement de pointage par rapport à la cible visée est aussi utilisée afin de déterminer l'origine du vecteur (Soechting & Flanders, 1989a, b). L'expérience réalisée par Vindras et Viviani (1998) illustre de façon élégante l'approche vectorielle en utilisant une telle mesure. La tâche imaginée par les auteurs consistait à atteindre pendant 160 essais une seule cible mais à partir de quatre bases de départ disposées en losange. Les participants pouvaient amorcer leur mouvement de pointage aussitôt que la cible apparaissait. Étant donné que celle-ci était présentée pendant seulement 200 ms, une grande partie du mouvement s'effectuait sans la vision de la cible. Le mouvement devait être effectué d'un seul trait, le plus rapidement et le plus précisément possible. Les auteurs ont noté que la trajectoire du mouvement était linéaire, ce qui supporte l'idée voulant que le mouvement soit planifié selon un vecteur. De plus, les réponses arrivaient à court de la cible tôt dans la pratique et dépassaient la cible tard dans la pratique. Dans les deux cas, la configuration des réponses respectait la configuration des bases de départ. Ainsi, pour les mouvements hypométriques, on observait un losange. Pour les mouvements hypermétriques, les réponses correspondaient à un losange inversé. Une telle correspondance entre la position initiale de la main et de la cible milite fortement en faveur d'une représentation de la cible centrée sur la main mais également en faveur de l'approche vectorielle.

Selon l'approche vectorielle, l'erreur de pointage serait causée non pas par la définition inadéquate de la cible dans un cadre égocentrique, tel que proposé par Soechting et Flanders (1989b), mais par une localisation inadéquate de la position initiale de la main (Ghilardi et al., 1995 ; Vindras, Desmurget, Prablanc, & Viviani, 1998). Comme la position finale est *reliée* par un vecteur à la position initiale, une localisation biaisée de la main aura un impact direct sur la position finale de la réponse. Ce type de proposition est bien en ligne avec les études démontrant l'avantage de voir sa main avant l'amorce du mouvement pour mieux situer la position de celle-ci (Jeannerod & Prablanc, 1983, Rossetti, Stelmach, Desmurget, Prablanc, & Jeannerod, 1994 ; voir Desmurget et al., 1998 pour une revue).

Outre le fait que les auteurs ne s'entendent pas sur la partie du corps par laquelle la cible est localisée de façon égocentrique, le plan sur lequel est tracé le vecteur diffère aussi selon les auteurs. Comme il a été mentionné précédemment, Soechting et Flanders (1989) suggèrent que le vecteur est tracé de façon intrinsèque (ou proprioceptive), soit en comparant deux postures du bras et de l'avant bras. D'autres auteurs, comme Bock et Eckmiller (1986) proposent plutôt que le vecteur serait tracé dans un plan extrinsèque, ou en d'autres mots, dans l'espace où s'effectue le mouvement, et ce, selon des coordonnées cartésiennes. L'amplitude et la direction du mouvement seraient donc déterminées selon des coordonnées externes au corps. Étant donné que des évidences expérimentales supportent ces deux points de vue, il est probable que le plan sur lequel le vecteur est tracé dépend des conditions expérimentales. À cet égard, Bédard et Proteau (sous presse) proposent que lorsque la position de la main sur la base de départ est fovéalisée avant l'amorce du mouvement, le vecteur serait programmé dans un plan extrinsèque.

Toutefois, lorsque la position de la main n'est pas disponible visuellement ou uniquement via la vision périphérique, le vecteur serait alors tracé dans un plan intrinsèque. Pour leur part, Desmurget, Rossetti, Jordan, Meckler et Prablanc (1997) proposent que les mouvements exécutés directement avec le doigt seraient planifiés dans un espace extrinsèque alors que les mouvements pour lesquels un outil est utilisé (pointeur, souris, manipulateur) seraient programmés dans un plan intrinsèque (voir toutefois Bédard & Proteau, sous presse). Enfin, Rossetti et al. (1995) proposent que l'origine du vecteur puisse être codée à la fois sous une forme extrinsèque ou intrinsèque. Cette proposition suppose toutefois que les deux sources d'informations soient présentes avant l'amorce du mouvement (la main doit être visible).

En bref, bien que la plupart des auteurs soient d'accord sur le fait que la cible et la main doivent être codées dans un cadre de référence commun, la partie du corps utilisée pour coder la position de la cible diffère selon les approches.[2] Certains auteurs (Ghilardi et al., 1995 ; Vindras et al., 1998) ont aussi mis en doute que l'erreur de pointage dans une situation où la main et la cible sont codées dans des cadres de références différents soit avant tout causée par une transformation sensori-motrice inadéquate tel que proposé par Soechting et Flanders (1989b). Malgré ces divergences, on peut toutefois affirmer que toutes situations où la cible et la main sont codées dans un cadre de référence commun (extrinsèque-extrinsèque, intrinsèque-intrinsèque) entraînent une diminution marquée de l'erreur de pointage par rapport à une situation où la cible est codée dans un cadre extrinsèque et que la main est codée dans un cadre intrinsèque par exemple.

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[2] Certains auteurs proposent même que la cible pourrait aussi être localisée par rapport à la tête (Grossberg & Kuperstein, 1989 ; Jeannerod, 1988), à l'axe médian-sagittal (Bartolomeo & Chokron, 1999) ou au tronc (Yardley, 1990).

### Contexte visuel

Le rôle du contexte pour la transformation de l'information de même que pour la programmation du vecteur (extrinsèque ou intrinsèque) n'a pas été étudié à notre connaissance. Toutefois, comme le contexte permet une meilleure estimation de la distance entre la base de départ et la cible (Coello & Magne, 2000), il est probable que la paramétrisation de l'amplitude du vecteur en soit par conséquent affectée.

### Vieillissement

On ignore à ce jour si le processus de transformation de l'information est affecté par le vieillissement. On a toutefois observé des problèmes au niveau du traitement de l'information proprioceptive avec l'âge (Chaput & Proteau, 1996 ; Proteau, Charest, & Chaput, 1994 ; Warabi, Noda, & Kato, 1986). Ce déficit pourrait affecter la localisation de la main dans un cadre de référence égocentrique. La présente thèse permettra de déterminer si la capacité de la personne âgée à réunir dans un même cadre de référence l'information provenant de la cible et de la main est affectée

## Impact du retrait de la vision de la cible

Les études précédentes ont démontré que la planification du mouvement de pointage se complique lorsque la position de la cible et celle de la position initiale de la main sont codées dans des cadres de référence différents. La difficulté provient des mécanismes mis en place pour localiser la cible et la main et transférer ces informations dans un même cadre de référence. Évidemment, le problème demeure le même lorsque la cible n'est plus visible. D'ailleurs, plusieurs évidences présentées plus haut ont été démontrées à l'aide d'une tâche où la cible n'était pas visible pendant le mouvement (par exemple, Soechting & Flanders, 1989a, b). Selon Soechting et Flanders (1989a, b), les processus impliqués lors des mouvements de pointage exécutés avec ou sans vision de la cible demeurent sensiblement les mêmes. Lorsque la cible n'est pas disponible pendant le mouvement de pointage, sa position est simplement remplacée par une représentation mnésique de celle-ci. Le retrait de la vision de la cible n'est donc pas mis en cause pour expliquer les erreurs obtenues lors de l'exécution de mouvement sans vision.

Pourtant, plusieurs auteurs ont démontré que l'exécution d'un mouvement de pointage vers une cible qui n'est plus visible est moins précise que pour le mouvement exécuté vers une cible visible (Adamovich, Berkinblit, Smetanin, Fookson, & Poizner, 1994; Berkinblit et al., 1995 ; Darling & Miller, 1993; Prablanc et al, 1986 ; Soechting & Flanders, 1989a). Desmurget et al. (1998) ont proposé que cette diminution de la précision est attribuable à la perte de l'information rétinienne provenant de la cible, laquelle permet un contrôle en temps réel (Goodale, Pélisson, & Prablanc, 1986) et une localisation de la cible plus précise que la seule présence des signaux extra-rétiniens (Bock, 1986). Cependant, il importe de noter que l'information sur la position de la cible est présente en mémoire (Elliott, Jones, & Gray, 1990a ; Elliott & Madalena, 1987 ; McIntyre et al., 1997, McIntyre, Stratta, & Lacquaniti, 1998) et que cette information pourrait possiblement être combinée aux signaux extra-rétiniens pour ainsi jouer un rôle similaire à celui joué par l'information rétinienne. La précision du mouvement dépendrait alors de la qualité de la représentation mnésique de la cible ou en d'autres mots, de la similitude entre l'information rétinienne et la représentation mnésique.

Dans les pages qui suivent, les deux processus principaux susceptibles d'influencer la qualité de la représentation de la cible en mémoire seront évalués.

Premièrement, l'encodage sera analysé, tout spécifiquement en fonction du temps de présentation de la cible. Par la suite, le maintien de l'information sera discuté. Une fois de plus, ces thèmes seront abordés en fonction du contexte visuel et du vieillissement.

## Encodage

Dans une situation où la cible disparaît avant l'amorce du mouvement, il importe d'encoder sa position en mémoire. L'encodage réfère à la transformation d'une représentation sensorielle en représentation plus durable en mémoire (Tulving, 1983). Avant de procéder à l'encodage de l'information visuelle, il importe de bien situer l'emplacement de la cible avant qu'elle ne disparaisse.

### Localisation de la cible

Les facteurs pouvant influencer la localisation d'une cible qui demeure visible pendant tout le mouvement de pointage ont été discutés précédemment. Toutefois, l'atteinte d'une cible se déroule fréquemment dans des conditions moins optimales. Tel est le cas, lorsque la cible n'est entrevue que pendant un bref instant. Dans cette situation, le temps alloué pour diriger son attention vers la cible et la fovéaliser est de première importance. À cet effet, Adam et al. (1993, 1995) ont manipulé le temps de présentation de la cible. Lors de leur première étude, la cible était présentée visuellement pendant un laps de temps variant entre 25 et 350 ms. Par la suite, la cible demeurait présente mais était masquée par l'ajout de 473 nouveaux points. La base de départ et le point de fixation étaient situés au milieu de cette grille. Le mouvement de pointage devrait être effectué en déplaçant un curseur à l'aide des flèches d'un clavier d'ordinateur. On a noté que le pourcentage de bonnes réponses augmente en fonction de l'augmentation du temps de présentation de la cible et de la diminution de la distance entre le point de fixation et la cible. En d'autres mots, les cibles les plus rapprochées nécessitent un temps de présentation plus court pour atteindre une performance maximale. De plus, on a observé une forte augmentation de la précision de la réponse manuelle (environ 25%) entre le temps de présentation de 25 ms et celui de 50 ms. Les auteurs interprètent cette augmentation de la précision en proposant que le système attentionnel entre alors en fonction. À partir d'un temps de présentation de 100 ms, on observe une nouvelle amélioration graduelle de la performance (environ 30%), laquelle serait attribuable à la fovéalisation de la cible qui requiert 100 ms. Les résultats de l'expérience 3 confirment cette dernière affirmation en démontrant que la performance lors d'un temps de présentation de 50 ms demeure inchangée peu importe que l'on permette ou non le mouvement des yeux. Les principaux résultats obtenus lors de cette étude ont été reproduits lors d'une deuxième étude en utilisant, cette fois, un mouvement de pointage avec curseur (Adam et al., 1995). Il faut retenir de ces résultats que le temps de présentation a un impact direct sur la précision du mouvement de pointage dirigé vers une cible non-visible.

### Contexte visuel

Par ailleurs, étant donné que la perception d'une cible est améliorée par la présence d'un contexte visuel riche (Conti & Beaubaton, 1980 ; Gnadt et al., 1991 ; Velay & Beaubaton, 1986), il est possible que ce contexte soit d'autant plus utile lorsque la cible n'est présentée que pendant un court instant. À cet effet, Honda (1990, 1997) propose que lorsqu'une cible est présentée pendant un bref instant (par exemple, 2 ms) tout juste avant, pendant ou après l'amorce d'une saccade, la perception de l'emplacement de cette cible sera biaisée vers la droite ou vers la gauche (Honda, 1990, 1997). Toutefois, lorsque cette même cible est présentée sur un contexte visuel (par exemple, une carte du Japon), l'erreur de perception diminue (Honda, 1993, 1999, voir aussi Hayhoe, Lachter, & Moller, 1992). Sur la base de ces observations, on peut supposer qu'un mouvement de pointage manuel vers cette cible serait également plus précis.

### Vieillissement

Chez les personnes âgées, le temps d'amorce de la saccade occulaire augmente (Moschner & Baloh, 1994 ; Morrow & Sharpe, 1993; Munoz, Broughton, Goldring, & Armstrong, 1998 ; Pratt, Abrams, & Chasteen, 1997; Warabi et al., 1986) et la vélocité maximale des saccades diminue (Moshner & Baloh, 1994 ; Morrow & Sharpe, 1993 ; Munoz et al., 1998). Par exemple, les personnes âgées présentent un temps d'amorce des saccades supérieur aux jeunes adultes variant entre 20 ms (Moschner & Baloh, 1994) et 100 ms (Warabi et al. 1986), en fonction des caractéristiques du stimulus. De plus, la vélocité maximale de la saccade peut diminuer jusqu'à 71°/s (de 486°/s pour les jeunes adultes à 415°/s pour les personnes âgées) pour une cible située à 30° (Moshner & Baloh, 1994). Ces résultats suggèrent que la localisation de la cible chez les personnes âgées est plus longue. Cette proposition sera évaluée dans le cadre de la présente thèse.

### Encodage

Le temps de présentation de la cible a aussi été étudié non pas en fonction de la localisation de la cible mais en fonction de la mémorisation de celle-ci. Le but était de déterminer si une présentation plus longue des cibles permettait non seulement une meilleure localisation mais également un encodage plus adéquat. À cet effet, Hanari (1995) a présenté à l'aide d'un tachitoscope une matrice de six points. Les stimuli demeuraient visibles pendant 50, 200 ou 350 ms. Après un délai d'attente de 50, 250 ou 500 ms, les participants devaient identifier l'emplacement de deux des six points. Les résultats ont révélé que pour le temps de présentation des stimuli le plus long, le délai d'attente n'avait aucun impact sur la précision des réponses alors que pour le temps de présentation le plus court, la performance se détériorait graduellement entre le délai de rappel de 50 ms et celui de 500 ms. Selon Hanari (1995), l'augmentation du temps de présentation faciliterait le maintien de l'information visuo-spatiale en favorisant le transfert de l'information d'un état de mémoire primaire telle la mémoire iconique (Elliott & Madalena, 1987; Sperling, 1960) ou la persistance visuelle (Coltheart, 1980) vers un état de mémoire plus durable comme le calepin visuo-spatial (Baddeley & Hitch, 1974). On ignore toutefois si l'augmentation du temps de présentation peut permettre un maintien de l'information sur une plus longue période que celles utilisées par Hanari (1995). Par exemple, il a été démontré que la présence d'un délai de plusieurs secondes entre la présentation de la cible et l'amorce du mouvement (exécuté sans la vision de l'effecteur) altère grandement le mouvement de pointage, généralement en diminuant la précision du mouvement (Elliott & Madalena, 1987, 2, 5, et 10 s; McIntyre et al., 1998, 500 ms, 5 s, et 8 s; Rossetti et al., 1994, tel que cité dans Rossetti, 1998 : entre 0 s et 8 s). Étant donné que le temps de présentation n'était pas manipulé, on ignore l'effet du temps de présentation de la cible sur le mouvement de pointage après un délai prolongé. Cet aspect sera l'objet d'une attention particulière lors de la présente thèse.

### Contexte visuel

À notre connaissance, le rôle du contexte visuel pour l'encodage de la position d'une cible a été étudié à une seule reprise, soit par Barry, Bloomberg et Hubner (1997).

Les participants à cette étude devaient pointer dans la noirceur, du bas vers le haut, vers une cible qui avait été vue avec ou sans contexte visuel. Le contexte était constitué d'un paysage de campagne avec une route le traversant au centre. Cette route était également alignée avec le plan médian sagittal des participants. La cible pouvait être localisée toujours au centre de la route ou à différentes positions aléatoires. Les auteurs ont démontré que l'exécution d'un mouvement de pointage vers une cible située à une position aléatoire sur le contexte était biaisée vers la droite, et ce, peu importe que l'atteinte s'effectue sans contexte ou avec contexte visuel. Par contre, le contexte visuel permettait de diminuer le biais lorsque l'atteinte s'effectuait vers les cibles situées au milieu du contexte visuel. Pour ces cibles, le mouvement de pointage était modifié par le contexte visuel malgré qu'il ne soit plus disponible visuellement. Selon les auteurs, le contexte favoriserait un meilleur encodage des cibles centrales en mémoire en renforçant la relation entre la position de la cible et la position du corps. Aucun auteur n'a évalué l'impact d'un contexte visuel en fonction du délai d'attente. Ainsi, on ignore si la présence d'un contexte peut favoriser un meilleur encodage de la position de la cible et ultimement un maintien plus adéquat de cette information.

### Vieillissement

Il a déjà été proposé que l'encodage était affecté par le vieillissement (Grady et al., 1995; Kornes & Magnussen, 1996). Ce déficit est en partie attribuable à la diminution de la vitesse de traitement de l'information avec l'âge (Salthouse, 1982). Toutefois, l'encodage de la position d'une cible dans le cadre d'un mouvement de pointage ne semble pas avoir été étudié chez la personne âgée. Dans le cas où la cible n'est présentée que pendant un bref instant, il est probable que les déficits d'encodage des personnes âgées affecte la qualité de la représentation mnésique de la position de la cible, ce qui pourrait résulter en une diminution de la performance de pointage. L'un des objectifs de la présente thèse est de déterminer si tel est effectivement le cas.

### Maintien

L'exécution d'un mouvement de pointage vers une cible qui n'est plus visible nécessite de maintenir l'information sur l'emplacement de la cible en mémoire sur une période de temps plus ou moins prolongée. Tel que précisé plus haut, lors de l'atteinte d'une cible maintenue en mémoire, on observe qu'une augmentation du délai de rappel entre la présentation des cibles et l'amorce du mouvement entraîne une augmentation de l'erreur de pointage (Elliott & Madalena, 1987, McIntyre et al., 1998, Rossetti et al., 1994, tel que cité dans Rossetti, 1998). L'erreur de pointage augmente également en fonction de l'augmentation de la distance de la cible par rapport à la base de départ (Adam et al., 1993, 1995 ; Adamovich et al., 1998 ; Messier & Kalaska, 1997; Prablanc et al., 1986). Cette diminution de la performance de pointage en fonction de l'amplitude du mouvement est appelée « l'effet de distance ». Afin de comprendre le rôle de la mémoire dans ces augmentations de l'erreur de pointage, il importe de bien comprendre les mécanismes reliés au maintien de l'information.

Afin de maintenir l'information en mémoire, l'humain utilise non pas une seule mais une multitude de mémoires différentes. Ainsi, se souvenir d'un rendez-vous ou de la fête de sa mère sont des tâches qui font appels à deux mémoires différentes, soit la mémoire prospective et la mémoire épisodique. Dans le cas du maintien d'une cible visuelle pendant une courte période, l'information pourrait être maintenue sous diverses formes selon la procédure expérimentale utilisée (présentation visuelle de la cible vs.

proprioceptive, Soechting et Flanders, 1989a) ou possiblement le délai entre la présentation de la cible et le rappel (Elliott & Madalena, 1987).

Tout d'abord, dans la situation où la main est visible pendant le mouvement de pointage mais non la cible, la cible serait maintenue à l'aide d'une représentation centrée sur les yeux. Tel que proposé par McIntyre et al. (1997, p.1615) « Le cerveau pourrait simplement comparer les paramètres (angle de vergence, disparité, accommodation) de la position perçue de la main avec les paramètres mémorisés de la position de la cible exprimés selon les mêmes termes » (traduction libre). L'erreur provenant de l'utilisation d'un tel type de représentation serait attribuable à une mauvaise estimation en vision binoculaire de la position de la cible et de la main.

Toutefois, l'exécution d'un mouvement de pointage alors que la cible n'est pas visible s'effectue bien souvent alors que la main est également non visible. Dans ce cas, on ignore toujours sous quelle forme la cible est maintenue. D'une part, plusieurs auteurs croient que la cible est codée dans un cadre égocentrique dès sa présentation et est maintenue sous cette forme jusqu'à son atteinte (Carrozzo et al., 1999 ; Chieffi & Allport, 1997). À cet effet, McIntyre et al. (1998) se sont intéressés à la partie du corps utilisée pour maintenir en mémoire la position de la cible. Lors de cette étude, les participants devaient pointer vers une cible située dans un environnement tridimensionnel. La cible était présentée pendant 1400 ms et l'amorce du mouvement s'effectuait après des délais de rappel de 500, 5000 ou de 8000 ms. Le mouvement de la main était visible dans une condition et non visible dans une autre condition. Lorsque le mouvement s'effectue alors que la main est visible, on dénote que l'axe de variabilité maximale est dirigé vers les yeux. Ce résultat confirme les résultats de McIntyre et al. (1997). Toutefois, lorsque la main en déplacement vers la cible n'est pas visible, l'axe de variabilité maximale du mouvement est alignée avec une position sise entre les yeux et l'épaule du participant. Ainsi, les auteurs rejoignent la position de Soechting et Flanders (1989a, b; voir aussi Soechting et al., 1990; Flanders et al., 1992). Les résultats indiquent que l'augmentation du délai de rappel entraîne une augmentation de la contraction des réponses (les positions finales des mouvements sont davantage rapprochées les unes des autres que ne l'est la configuration des cibles). Cette contraction augmente dans un axe dirigé entre la tête et les épaules. Selon les auteurs, ces résultats suggèrent que la représentation mnésique de la cible est spécifiée selon un cadre de référence égocentrique.

À l'opposé, certains auteurs proposent lorsqu'un délai prend place entre la présentation de l'information et le rappel, celle-ci serait maintenue de façon allocentrique, c'est-à-dire que l'ensemble de l'information disponible serait maintenu, possiblement sous une forme visuelle (Bridgeman, 1991 ; Elliott & Calvert, 1990 ; Elliott, et al., 1990a ; Goodale & Milner, 1992). La cible serait alors maintenue en fonction des éléments contextuels l'entourant et non de façon isolée. Pour les délais très courts (inférieur à 1 seconde), une représentation visuelle (iconique) de la cible et de son environnement serait maintenue en mémoire (Elliott & Calvert, 1990; Elliott & Jaeger, 1988; Sperling, 1960). Elliott et Madalena (1987) ont été les premiers à démontrer qu'une telle représentation pouvait être utilisée dans le cadre d'un mouvement de pointage. Les participants de cette étude devaient pointer une cible avec un stylet. La tâche était réalisée dans une chambre noire, alors que la cible à atteindre était visible ou ne l'était pas. Dans ce dernier cas, les participants amorçaient leur mouvement 0, 2, 5 ou 10 secondes après le retrait de la cible à atteindre. Elliott et Madalena (1987) ont démontré qu'un délai de 2 secondes entre la présentation de la cible et l'amorce du mouvement d'atteinte entraînait une erreur de pointage beaucoup plus élevée que lorsque la cible était retirée alors que le participant amorçait son geste d'atteinte. Les auteurs ont proposé que la meilleure précision spatiale des participants pour la condition sans délai, comparativement aux autres conditions expérimentales, était due au fait que la position de la cible à atteindre était disponible en mémoire iconique et que cette information était utilisée pour guider le mouvement vers la cible. Cependant, comme l'indiquent les résultats, le maintien en mémoire iconique de l'emplacement d'une cible est très court puisque cette information ne serait plus aussi utile au contrôle du mouvement après un délai de 2 secondes dans le noir (voir aussi DiLollo et Dixon, 1988, Irwin et Yeomans, 1986).

La proposition voulant que l'information concernant la position de la cible est véritablement maintenue en mémoire iconique a été soutenue par une deuxième étude au cours de laquelle une procédure de masquage a été utilisée (Elliott, Calvert, Jaeger, & Jones, 1990b, expérience 2). Dans le cadre de cette étude, la cible était visible pendant 150 ms, puis un masque était introduit. Les participants devaient compléter leur mouvement dans un temps variant 500 et 700 ms. Étant donné que le temps de réaction moyen était de 350 ms, le mouvement était amorcé après l'introduction du masque. L'erreur spatiale était significativement plus faible lorsque la présentation de la cible n'était pas suivie du masque (16,3 mm versus 19,8 mm). Ce résultat confirme qu'une représentation visuelle de la cible peut faciliter l'exécution du mouvement de pointage.

### Contexte et vieillissement

Dans l'éventualité où la proposition voulant que la position de la cible soit maintenue dans un cadre allocentrique est véridique, tel que le laisse supposer certains auteurs (Bridgeman, 1991 ; Elliott & Calvert, 1990 ; Elliott, et al., 1990a ; Goodale & Milner, 1992), la performance des personnes âgées pourrait alors être déficitaire. En effet, plusieurs études réalisées en psychologie expérimentale tendent à démontrer que bien que le maintien de l'information dans un cadre de référence égocentrique soit préservé avec l'âge (Ozekes & Gilleard, 1989 ; Uttl & Graf, 1993), le maintien de l'information dans un cadre de référence allocentrique serait rendu plus difficile par le vieillissement (Cherry & Park, 1989 ; Zelinski & Light, 1988). Desrocher et Smith (1998 ; voir aussi Desrocher, 1999) ont été parmi les premiers à démontrer au sein d'une même étude, la dissociation entre le maintien de l'information égocentrique et de l'information allocentrique avec l'âge. Lors de cette étude, 60 paires d'objets étaient présentées en succession. Les objets pouvaient être placés à six emplacements prédéterminés. Chaque paire était présentée pendant quatre secondes. Les participants devaient ensuite compter à rebours pendant quatre secondes avant que la paire suivante ne soit présentée. Après la présentation des soixante paires d'objets, un délai de 30 minutes était imposé pendant lequel les participants effectuaient une autre tâche. Par la suite, la moitié des participants devaient rappeler l'emplacement de chacun des objets de façon individuelle et l'autre moitié devaient rappeler les objets en paires.

Le rationnel derrière cette procédure était que la première forme de rappel était de nature égocentrique (les participants devaient seulement rappeler si l'objet était à leur droite ou à leur gauche et à quelle distance l'objet se trouvait par rapport à eux-mêmes) tandis que la deuxième forme de rappel était de nature allocentrique puisque les participants pouvaient utiliser l'un des deux objets pour situer l'autre. Les résultats ont indiqué que les jeunes adultes rappelaient plus d'objets lors de la condition allocentrique que les personnes âgées alors que pour la condition égocentrique, aucune différence n'a été observée entre les deux groupes d'âge. Ce type de résultats met en lumière une dissociation entre le maintien d'informations allocentrique et égocentrique avec l'âge. Les personnes âgées éprouveraient des difficultés à maintenir l'information visuo-spatiale dans un cadre de référence allocentrique mais non dans un cadre de référence égocentrique. En d'autres mots, l'utilisation du contexte entourant la cible serait plus difficile avec l'âge. Toutefois, on ignore si la difficulté provient de l'utilisation de l'information allocentrique en vue de planifier le mouvement ou seulement du maintien d'une représentation de la cible et de son contexte en mémoire. L'un des objectifs de la présente thèse est de tenter de répondre à cette question.

## Objectifs

Les études présentées dans le cadre de la présente thèse ont été réalisées afin de déterminer le rôle de l'encodage et du maintien de la position d'une cible lors d'un mouvement effectué sans vision de la cible, du contexte visuel environnant ou de la main du participant. La présente revue de littérature a mis en lumière certains facteurs susceptibles d'affecter à la fois l'encodage et le maintien de la position d'une cible (et de son contexte) en mémoire. Parmi ces facteurs, on retrouve le temps de présentation de l'information relative à la cible (étude 1), le délai de rappel (études 1 et 2), l'effet de distance, la présence d'un contexte visuel pendant la présentation de la cible (études 3) et pendant l'exécution du mouvement (études 3 et 4), et l'âge des participants (études 1 à 4).

L'étude de ces facteurs et de leurs impacts sur la représentation mnésique devrait permettre de déterminer si l'information est maintenue sous une forme égocentrique (Carrozzo et al., 1999 ; Chieffi & Allport, 1997 ; McIntyre et al. 1997, 1998) ou sous une forme allocentrique (Bridgeman, 1991 ; Elliott & Calvert, 1990, Elliott et al., 1990a ; Goodale & Milner, 1992) lors de la réalisation d'un mouvement de pointage vers une seule cible. Nous posons l'hypothèse que la représentation visuelle (ou allocentrique) de la cible devrait profiter d'une augmentation du temps de présentation visuelle de la cible et de la présence d'un contexte visuel lors de la présentation et de l'exécution du mouvement. Ces manipulations expérimentales pourraient potentiellement favoriser un meilleur encodage et maintien de la position de la cible en permettant la création d'une représentation visuelle plus riche de celle-ci. De plus, le mouvement de pointage réalisé selon ce type de représentation devrait être moins précis et plus variable chez les personnes âgées par rapport aux jeunes adultes.

Toutefois, dans le cas où la cible est maintenue sous une forme égocentrique, l'augmentation du temps de présentation ne devrait pas favoriser un maintien plus adéquat de la position de la cible puisque celle-ci est maintenue sous une autre forme que visuelle. Dans le même sens, la présence d'un contexte visuel ou l'âge des participants ne devraient pas modifier la performance de pointage de façon importante. Par ailleurs, l'effet de distance pourrait s'expliquer par l'augmentation du temps de mouvement nécessaire à l'atteinte des cibles éloignées. En effet, le mouvement de pointage est susceptible d'interférer avec le maintien de la position de la cible dans un cadre égocentrique puisque ces deux opérations s'effectueraient sous un même cadre de référence. Cette possibilité sera évaluée.

# CHAPITRE 2

## ARTICLE 1

# The Effects of Target Presentation Time, Recall Delay and Aging on the Accuracy of Manual Pointing to Remembered Targets

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# Abstract

The goal of the present study was to determine whether the retention of a target location in memory for motor control purposes would be facilitated by an increase in target presentation time and whether increasing the recall delay since the last exposure to the target would have deleterious effects on aiming accuracy and or variability. Also, we wanted to determine whether these effects would be mediated by aging. The results of two experiments revealed the existence of a short-lived (< 1 s) visual representation of target location. In addition, the results suggest that the nature of this representation dictates a movement strategy favoring higher peak movement velocity. None of the effects reported in the present study were affected by age, suggesting that the coding and retrieving processes of target location in memory for motor control purposes are not affected by age.

# The Effects of Target Presentation Time, Recall Delay and Aging on the Accuracy of Manual Pointing to Remembered Targets

Manual aiming tasks have been used extensively for studying human movement control. Performing this apparently simple task puts into play a series of complex processes. When different targets are used from one trial to the other, target presentation first captures one's attention (Adam, Paas, Ekering, & van Loon, 1995). Then, this target is foveated, which enables one to better determine its location based on a combination of both retinal and extra-retinal information (Prablanc, Pélisson, & Goodale, 1986). At this moment, the location of the target is coded in an exocentric frame of reference (Jeannerod, 1988; see also Desmurget, Pélisson, Rossetti, & Prablanc, 1998, for a recent review). If aiming is performed while one's hand is also visible, the hand's location is also coded in the same exocentric frame of reference, which results in optimal aiming accuracy (Elliott, Carson, Goodman, & Chua, 1991; Desmurget, Rossetti, Prablanc, Stelmach, & Jeannerod, 1995; see also Proteau, 1992 for a review).

Performing the same task, but this time while vision of one's hand is not permitted, puts into play an additional series of processes. The location of one's hand is readily available in an egocentric (or proprioceptive) frame of reference, and it is thought that the location of the target, available in an exocentric frame of reference, must be transferred into the same egocentric frame of reference (Jeannerod, 1988). It has been shown that this transformation of the location of the target from an exocentric to an egocentric frame of reference is prone to errors, which at least partially explains why aiming movements performed without vision of one's hand are less accurate and more variable than movement performed in a normal visual context (Proteau & Carnahan, in press; Soechting & Flanders, 1989a, b; Vindras & Viviani, 1998)[i].

Aiming error and variability increase further if one's hand is not visible and the target to be reached disappears prior to or during movement execution (Adamovich, Berkinblit, Smetanin, Fookson, & Poizner, 1994; Darling & Miller, 1993; Soechting & Flanders, 1989a). Desmurget et al. (1998) proposed that this further increase in error is caused by the loss of retinal information about the location of the target which permits a more accurate location of the target than extra-retinal signals alone (Bock, 1986), and also a more efficient on-line control of the movement (Goodale, Pélisson, & Prablanc, 1986). However, one must consider that information about target location is also available in memory (Elliott & Calvert, 1992; Elliott & Madalena, 1987) and that presumably it might be combined with the available extra-retinal signal to update its egocentric representation as time unfolds. Hence, in such instances, movement accuracy would be a function of the quality of the memory representation about target location.

If a target disappears shortly after its presentation, we should expect an increase in aiming error in comparison to when the target is visible throughout the movement. However, this increase in error would be mediated by an increase in target presentation time. For instance, if target presentation time is long enough for the participant to initiate a visual saccade towards it, aiming accuracy will be better than when the target disappears before the saccade initiation (Adam et al., 1995; Adam, Ketelaars, Kingma, & Hoek, 1993), presumably because of better target localization. In addition, the increase in aiming error noted when the target is not visible can be caused by a less than perfect encoding of target location. Here encoding refers to the transformation process of an event in a relatively durable memory trace (Tulving, 1983). In this regard, increasing the presentation time of visuo-spatial information has been shown to result in a more stable and longer lasting representation of this information in memory (Hanari, 1995, 1996). Specifically, Hanari (1995) used a tachitoscope and presented stimuli made-up of six small dots presented at random locations. The stimuli remained visible for 50, 200 or 350 ms. On each trial, participants were asked to identify the locations of two of these dots following a recall delay of 50, 250, or 500 ms after stimulus extinction. The results indicated that the recall delay had no influence on recall accuracy for the longer stimulus presentation time, whereas for a stimulus presentation time of 50 ms, performance deteriorated from the 50 ms to the 500 ms recall delay. Thus, it would appear that increasing target presentation time facilitates maintenance of visuo-spatial information, possibly in iconic memory.

Iconic memory is thought to retain the raw characteristics of a visual stimulus for a very brief period of time (see Coltheart, 1980 for a review). It has been shown that information about target location can be stored in iconic memory and used for movement control once the target has disappeared. In that regard, pointing to a remembered target location without vision of one's hand available is more accurate when movement is initiated very shortly following target extinction than when the recall delay that takes place between target presentation and movement initiation of aiming movements is increased (Elliott & Madalena, 1987; McIntyre, Stratta, & Lacquaniti, 1998; Rossetti, Lacquaniti, Carrozzo, & Borghese, 1994, as cited in Rossetti, 1998). The apparent contradiction between Hanari's (1995) results and those reported above might have resulted from procedural differences. Specifically, the recall delays used in all of the above studies were much longer than those used by Hanari (1995), (Elliott & Madalena, 1987, 2, 5, and 10 s; McIntyre et al., 1998, 500 ms, 5 s, and 8 s; Rossetti et al., 1994 : between 0 s and 8 s), and target presentation time was either not controlled or not experimentally investigated, which makes it impossible to evaluate the effects of the recall delay as a function of target presentation time. Specifically, it makes it impossible to determine whether a longer target presentation time would enable one to register information about target location in a longer lasting memory than iconic memory. The identity of this longer lasting memory system is not of central importance in the framework of the present study. However, a likely candidate would be the visuo-spatial scratchpad (Baddeley, 1986). This memory system is thought to be a sub-component of the working memory that stores and processes visual and spatial information and that it would be involved in retaining information about a visual scene and a potential target (see Logie, 1994 for a review).

Finally, it is also possible that pointing accuracy to extinguished targets might be affected by the age of participants because encoding (Kornes & Magnussen, 1996) and the retention of visuo-spatial information (Cherry & Park, 1989; Cherry, Park, & Donaldson, 1993; Hoyer, 1990; Smyth & Park, 1990; West, 1986) is affected by aging. Specifically, Cherry et al. (1993) asked older and younger participants to remember the location of 24 objects that could be presented in each of 64 different locations. Success rate of older participants was of 44.7% in comparison to 66.5% for younger participants suggesting a deficit in the retention of visuo-spatial information with aging. Although the task used by Cherry et al. (1993) is very different from an aiming task to a single target location, it suggests that pointing to a remembered target location might be affected by age. One objective of the present study is to determine whether pointing to remembered target locations is affected by aging.

# EXPERIMENT 1

As indicated above, when a manual aiming movement is performed while the target is no longer visible, retinal information about its location can be replaced by a memory representation of it, which is combined with extra-retinal information. The main objective of the present study was to determine if, and how, factors known to affect the quality of the memory representation of visuo-spatial information would influence aiming accuracy. If it is only localization of the target that determines aiming accuracy to a no longer visible target, then aiming should be more accurate/less variable for a longer than for a shorter target presentation time, regardless of the recall delay. However, Hanari's (1995) results suggest that a longer target presentation time leads to increased maintenance of visuo-spatial information in memory. Because of the task and the overall short recall delays used by Hanari (1995), and the fact that studies in which an aiming task was used did not manipulate target presentation time per se (Elliott & Calvert, 1992[ii]; Elliott & Madalena, 1987; McIntyre et al., 1998), it is not clear whether an increase in target presentation time would result in a better memory representation of the target accurate enough to ensure fine motor control even after long recall delays. If it is the case then, increasing the recall delay should result in a lesser increase in aiming error and aiming variability for longer than for shorter target presentation times. Finally, because aging seems to result in a decrease in both encoding and retention processes of visuo-spatial information, the above effects should be larger for older than for younger adults.

# Method

## Participants

Ten younger adults (M: 20.5 years old, SD : 1.18 years) and ten older adults (M: 70 years old, SD: 4.24 years) took part in this study. All participants were right handed, had good upper limb mobility and did not have any visual deficit except those corrected by prescription lenses. The younger participants, all students in the Département de kinésiologie at the Université de Montréal, were recruited in an introductory psychomotor behavior class. Older participants were recruited from a pool of participants who had previously taken part in motor control experiments in our laboratory. All older participants lived in their own residences and reported being in good health. The students received bonus points for their participation in this study whereas the older participants were paid (30$). The participants were unaware of the purpose of the study.

## Tasks and apparatus

The task consisted in moving a cursor illustrated on a computer screen (Mitshubishi Color Diamond Pro, 37 inches) towards one of nine possible targets presented on the same computer screen (Figure 1). All targets were white (on a black background), with a width of 3.2 mm and a height of 64.5 mm (sustaining a visual angle of 0.366° and 7.35° of visual angle, respectively). The distance between each target was 22.5 mm. They were located at a minimum of 129 mm from the starting base and at a maximum of 309 mm.

Displacement of the cursor occurred when the participant moved a pointer with his or her left hand toward the right of the screen on an axis parallel with the screen

(Figure 1). The cursor illustrated on the screen was aligned with the pointer so that the displacement of the cursor corresponded perfectly (a ratio 1:1) to the displacement of the pointer. A cardboard shield prevented the participants from viewing their hand or their pointer.

The pointer was connected to an optical encoder (U.S. DIGITAL, model S2-1024-NT, sampling rate of 500 HZ, spatial precision of 0,17 mm), sampled by a microcomputer. The video computer card used was Matrox Millenium II with a resolution of 1024 X 768 pixels. For the whole experiment, participants wore liquid crystal goggles (Plato Translucent Technologies), which changed from transparent to translucent immediately after the presentation of the target, thus instantaneously (~ 3 ms) depriving participants of visual contact with the target.

Insert Figure 1 approximately here

Procedure

Participants sat in front of the computer screen. They were asked to gaze at the screen before the beginning of each trial. We did not use a fixation point to prevent the possibility that visual persistence of this point would interfere with the task. At the beginning of each trial, the participant had to hold the pointer between the thumb and the index finger of his or her non-dominant hand. Once the pointer was stabilized at the starting position, the target was presented on the computer screen and remained visible for either 50 ms or 500 ms. The target disappeared from view when the goggles' lenses went from their transparent to their translucent state (~3 ms). Following disappearance of the target, the participant was to wait for a delay of either 0 ms, 100 ms, 1000 ms or

10000 ms before initiating his or her movement towards the target. An auditory stimulus indicated when movement could begin.

The beginning of the pointing movement was defined as the moment at which the velocity of the pointer exceeded 3 cm/s whereas the end of the movement occurred when the velocity of the pointer decreased below 3 cm/s for at least 1000 ms. This procedure allowed participants to correct their movement if they so desired. It should be noted that the Experimenter informed the participants to put the emphasis on the accuracy of their movement and not on its velocity.

The experiment began with a practice block of 16 trials performed in normal vision (without goggles) ; it was followed by a block of 16 trials performed with the goggles in their translucent state. Practice trials were carried out on targets located at intermediate positions compared to the targets used in the experimental phase. For each block of practice, four trials were carried out for each delay. For each of these four trials, the targets were visible for 500 ms for the first trial and then, the presentation time decreased to 300 ms, 150 ms and 50 ms for the next trials of practice. The objective of the first block of practice was to familiarize participants with the pointing task. The second block of practice was used to familiarize participants with the occlusion procedures. For the second practice block, participants were informed of the spatial accuracy of their movement.

Following the practice phase, the participants performed 360 experimental trials. These trials were presented in eight successive blocks (2 target presentation times x 4 delays) of 45 trials each. The order of presentation of the different experimental conditions was randomized across participants. In each experimental block of trials, the participants carried out five trials towards each of nine possible targets. The order of presentation of the targets was randomized within each block with the restriction that each target be presented once in each successive series of five trials. The targets were localized within the participant's left hemispace. No knowledge of results was provided during this experimental phase. Each experimental session lasted approximately 90 minutes. A 10-minute rest period took place following the fourth experimental block of trials.

Dependent variables. In the present study we evaluated the variable error and the constant error of aiming. The variable error is a measure of within-participant variability in aiming. It is considered to reflect forgetting of the location of the target (Guay, 1986; Guay & Hall, 1984) and is the main dependent variable of the present study. The constant error is used to determine whether aiming movements show a bias (undershooting or overshooting of the target). In the framework of the present study, a large constant error is seen as reflecting a poor transformation of the location of the target from an allocentric to an egocentric frame of reference (Soechting & Flanders, 1989a, b).

In addition, we also analyzed a series of kinematic landmarks characterizing the aiming movement. The displacement data of the cursor over time were first smoothed using a fourth order recursive Butterworth filter with a cutting frequency of 10 Hz. The smoothed data were then numerically differentiated once using a central finite technique to obtain the velocity profile of the aiming movement and then a second time to obtain its acceleration profile. From these profiles, we measured the movement peak velocity, the time required by the participants to complete the task (movement time), the time spent in the acceleration and in the deceleration phases, and the number of on-line corrections to the ongoing movement. Movement time is defined as the delay taking place between movement initiation and movement completion. As presented above, movement initiation was defined as the moment at which the velocity of the pointer exceeded 3 cm/s whereas movement completion occurred when the velocity of the pointer decreased below 3 cm/s for at least 1000 ms. The time spent in acceleration and in deceleration corresponds to the portion of movement time occurring before and after peak velocity had been reached, respectively. Finally, in the framework of the present study a correction was detected when one of the three following situations occurred. First, a correction was detected when the velocity profile went from positive to negative, indicating a movement reversal. Second, a correction was detected when the acceleration profile crossed the zero line for a second time, indicating a movement lengthening. Finally, when the acceleration profile showed a discontinuity during the deceleration phase of the movement, a trial was determined as showing a correction when the jerk profile went from negative to positive at the moment of occurrence of the discontinuity noted on the acceleration profile. We computed the proportion of trials showing at least one correction.

## Results

Each dependent variable was submitted independently to 2 x 2 x 4 ANOVA using repeated measurements on the last two factors. The first factor corresponded to the two age groups used in the present study. The second factor was the target presentation time (50 ms vs. 500 ms) and the last factor was the delay between occlusion of the target and movement initiation (0 ms, 100 ms, 1000 ms, and 10000 ms). Target location was not considered as an experimental factor in these analyses. All significant main effects and interactions were further delineated using the Newman-Keuls technique ($\underline{p} < .01$). The results of one older participant were withdrawn from all analyses because the data obtained from this participant differed by more than two standard deviations from the mean of his or her group. None of the dependent variables was affected by age ($\underline{p} > .09$; see Table 1)[iii]. Mean results obtained for all dependent variables as a function of the target presentation time and of the recall delay are presented in Table 2.

Insert Tables 1 and 2 approximately here

### Variable error

The ANOVA only revealed significant main effects of the target presentation time, $\underline{F}$ (1, 17) = 9.6, and of the recall delay , $\underline{F}$ (3, 51) = 5.93. The first effect indicates that variable error is larger for the shorter than for the longer target presentation time (24.8 mm vs. 19 mm, respectively). The second effect indicates that variable error was larger after the longer than after the three shorter recall delays that did not differ from each other. As illustrated in Figure 2, this was true for both the 50 ms and the 500 ms target presentation times.

Insert Figure 2 approximately here

### Constant error

The ANOVA only revealed a significant main effect of the recall delay, $\underline{F}$ (3,51) = 6.6. This main effect indicates that participants overshot the location of the target for the two shorter recall delays (29.3 mm and 31 mm, respectively) in comparison to their responses for the two longer recall delays (8.6 mm and -3 mm, respectively). There was no difference in constant error within each one of these two groupings.

Movement kinematics

As illustrated in Figure 3, movement peak velocity is higher for the three shorter recall delays than for the 10000 ms recall delay, F(3, 51) = 7.44. Nonetheless, movement time was not significantly modified by any of the independent variables (p > .05).

Insert Figure 3 approximately here

The ANOVA computed on the time spent during the acceleration phase of the movement revealed a significant interaction between the target presentation times and the recall delays, F (3, 51) = 10.52. This interaction revealed that participants spent less time in the acceleration phase for a target presentation time of 500 ms and a recall delay of 10000 ms than for any other combination of these two factors. The experimental manipulations did not affect the time spent in deceleration (p > .09) nor the number of movements showing at least one correction. Concerning this last dependent variable, the only effect that approached significance was that corrections were more frequent for the 10000 ms recall delay than for the 100 ms and the 1000 ms recall delay (62%, 57%, 57%, and 67% for the 0 ms, 100 ms, 1000 ms, and 10000 ms, respectively), F (3, 51) = 3.85, p = .015.

## Discussion

The goal of the present study was to determine whether factors known to affect the quality of the representation of visuo-spatial information in memory influence pointing accuracy. Two factors were selected to manipulate the quality of this representation: target presentation time that influences the encoding of visuo-spatial information in memory, and the recall delay that influences the maintenance of this information in memory. In addition, we had proposed that aging could influence both these processes.

The results of the constant error of pointing indicated that participants overshot the target when short recall delays were used but that this bias was significantly reduced when longer recall delays were used. The fact that this bias decreased for longer recall delays has been reported in previous research (McIntyre et al., 1998; see also Chieffi, Allport, and Woodin, 1999) and has been associated to a perceived contraction of the working space as a function of time. The fact that this contraction occurs in the direction of the starting base could be associated to a bias in the transformation of the target from a viewer-centered frame of reference (based on retinal and extra-retinal cues; McIntyre et al., 1998; Carrozzo, McIntyre, Zago, & Lacquaniti, 1999) to a body-centered frame of reference [based on the location of one's hand (Chieffi et al., 1999; Ghilardi et al., 1995; Vindras & Viviani, 1998) or of one's arm (McIntyre et al., 1998; Carrozzo et al, 1999)] but also to a bias in the perceived location of one's hand (Vindras, Desmurget, Prablanc, & Viviani, 1998; Wann & Ibrahim, 1992). However, it is unclear whether it affected only movement planning processes or also error correction processes. One goal of Experiment 2 of the present study will be to gain further insight in that regard.

More importantly in the framework of the present study, and congruent with our hypothesis, increasing target presentation time resulted in a decrease in pointing variability. This decrease in pointing variability with an increase in target presentation time does not appear to be related to the encoding of target location in a more lasting store as target presentation time increases. If such had been the case, the advantage found for the longer target presentation time should have increased as a function of an increase in recall delay, resulting in a significant target presentation time by recall delay interaction. This was not the case. Rather, consistent with the proposition of Adam and his colleagues (Adam et al. 1995), it appears that increasing the target presentation time from 50 ms to 500 ms permitted participants to foveate the target before it disappeared which resulted in a more stable representation of its location.

This aspect of our results is in contradiction with previous results reported by Hanari (1995) who showed that an increase in target presentation time from 50 ms to 500 ms resulted in a better performance for the longer recall delay he had used (i.e., 500 ms). This difference between the results of the present experiment and those reported by Hanari (1995) could most likely be explained by important procedural differences. For instance, in Hanari's study, pinpoint accuracy was less important than in the present study because participants did not have to point accurately at the location of remembered targets but rather had to draw on a sheet of paper the position of these targets. More importantly, the utilization of multiple targets in Hanari's study might have resulted in the target location being coded in a visuo-spatial frame of reference, which would explain why increasing target presentation facilitated performance. The longer the target presentation time, the better one is able to encode the location of multiple targets in relation to one another. Finally, the much longer recall delays used in the present study in comparison with Hanari's (1995) study, might explain the contradictory results. These differences between Hanari's (1995) study and the present experiment suggest that the nature of the information to be coded (one vs. many targets; required accuracy) and the period over which this information has to be maintained might influence how target information is coded in memory.

In that vein, the results of the present study indicate that a visual representation of target location is used for short recall delays. Support for this position comes from the observation that in the present study movements performed after short recall delays (0 ms and 100 ms) resulted in both relatively fast and minimally variable pointing movements, whereas increasing the recall delay to 10000 ms resulted in both a decrease in peak velocity and an increase in pointing variability (see Figure 3). The sole fact that movements performed at a higher velocity were less variable than those performed at a lower velocity is in itself important, because it is unusual (Meyer, Smith, & Wright, 1982; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). One could argue that higher peak velocities for the shorter than for the longer recall delays were a consequence of the fact that shorter recall delays resulted in a target overshoot whereas longer recall delays resulted in a target undershoot. This is a possibility because longer movements are generally associated with higher peak velocities. However, this explanation is doomed when it comes to explaining why longer and faster movements are less variable than shorter and slower movements. Rather, this finding suggests that shorter recall delays enabled the participants to plan and/or to control their movement based on target information stored in iconic memory (Elliott & Madalena, 1987). Because of the short duration of information in iconic memory (less than 300 ms; DiLollo & Dixon, 1988 ; Irwin & Yeomans, 1986; Kihutchi, 1987) increasing movement velocity would be an efficient strategy to ensure pointing accuracy, and as a side effect would result in a decrease in pointing variability. In conclusion, it appears that the increase in movement variability that usually results from increasing the velocity of one's movement is off-setted (and more) by the gain resulting from planning/performing this movement while a vivid representation of the target location is available in iconic memory.

The proposition that iconic memory can be used to ensure pointing accuracy of movements performed while the target is no longer visible has been supported by results reported by Elliott, Calvert, Jaeger, and Jones (1990, experiment 2) who used a masking procedure. Specifically, the target to be reached was visible for 150 ms and participants were asked to initiate their movement as they pleased but with the restriction that it be completed in a movement time ranging between 500 ms and 700 ms. Because participants had a mean reaction of 350 ms, movements were initiated after the mask introduction. The radial error of pointing was significantly lower when target presentation was not followed by a mask (16.3 mm vs. 19.8 mm) indicating that a visual representation of the location of the target could facilitate pointing accuracy in the absence of the actual target. Unfortunately, Elliott et al. (1990) did not also include a recall period long enough to dissipate any possible effect of iconic memory on pointing performance. Eliminating the masking effect described above in such a condition would lend added support to the proposition that iconic memory plays an important role in ensuring pointing accuracy when the actual target has just been withdrawn. Specifically, Lowe (1975) showed that a masking procedure did not influence recall performance when the mask is introduced 1000 ms after target offset. The long delay that preceded the introduction of the mask probably permitted the participants to encode the stimulus in a longer lasting format unaffected by the masking procedure. Thus, pointing accuracy should remain similar regardless of whether a mask is presented or not following target extinction.

Finally, the results of this first experiment indicated that encoding of target location in memory is not affected by age. Rather, our results suggest that older individuals are as efficient as younger ones in pointing to briefly seen targets, and this regardless of the recall delay. A similar result has been reported by Lovelace and Aikens (1990) for a recall delay of 2 s.[iv] Our results add to those of these authors by indicating that this is the case even for very short target presentation times and long recall delays.

## EXPERIMENT 2

In Experiment 1, it is possible that pointing movements initiated after a short recall delay were controlled on the basis of information about target location that was available in iconic memory whereas movements initiated after a long recall period were based on a longer lasting representation of the target location. When a short recall delay has been used, it is likely that participants performed movements at a higher peak velocity than for a longer recall period in order to use the information available in iconic memory for controlling their ongoing movement. Considering that information stored in iconic memory deteriorates quickly (DiLollo & Dixon, 1988 ; Irwin & Yeomans, 1986; Kihutchi, 1987) such a strategy would appear to be an efficient one. This is especially so if one considers that these movements, although performed at a higher velocity, were less variable than slower movements which, because of a long recall delay, could not have been performed based on iconic storage information. The first goal of this second experiment was to test this hypothesis. To reach our goal we used a masking procedure similar to that used by Elliott et al. (1990). If this masking procedure results in a decrease in movement peak velocity and/or an increase in pointing variability in comparison to a no mask condition, when short recall delays are used but not for a long recall delay (see Lowe, 1975), then confirmation that different memory systems were used as a function of the recall delay would be obtained. As in Experiment 1, our second goal was to determine whether aging would influence coding of target location in memory. Given the non-significant difference found between the two age-groups in Experiment 1, a replication of this finding appears important for any clear conclusion to be made. Finally, we wanted to determine if the pattern of biases found in the first experiment (i.e., constant error) would be replicated and whether they reflect biases originating from movement planning and/or error correction processes.

## Method

### Participants

Ten younger (M : 23.9 years old, SD : 2.28 years) and 10 older adults (M : 72 years old, SD : 5.48 years) took part in this experiment. Selection rules were similar to Experiment 1.

### Task, apparatus and procedures

The task, apparatus, procedures, and dependent variables were largely similar to those used in Experiment 1. The first notable modification was that within each block of trials, target presentation was followed by a visual mask for one half of the trials. For the masked trials, the computer screen turned white, which was the same color as the target, for a duration of 100 ms following target extinction (see Figure 4 for the time course of the presentation of the target, introduction of the mask, and recall delays).

Insert Figure 4 approximately here

As in Experiment 1, target presentation time was of either 50 ms or 500 ms. However, we used only two recall delays before movement initiation could take place, a short one (100 ms) and a long one (10000 ms). The experiment began with a practice block, which consisted in 8 trials performed under normal visual afferent information (no goggles) in order to familiarize the participants with the apparatus. It was followed by a second practice block of 8 trials performed while the goggles were in their translucent state. This second block of practice was used to introduce the experimental procedures. For this block, each trial was followed with knowledge of results concerning its terminal accuracy. After completion of the practice blocks, each participant completed 144 experimental trials. For one half of the trials, participants completed 18 trials for each combination of target presentation time and recall delay with no mask. For the second half of the trials, participants also completed 18 trials for each combination of target presentation time and recall delay, but under the masking procedure. Half of the participants began the experiment with the masked procedure whereas the other half began the experiment in the no-masked condition. For both the masked and the no-masked procedures, the order of presentation of the different combinations of target presentation time and of recall delay was randomized across participants. For each of these combinations, participants completed two trials for each one of the nine targets used in Experiment 1.

## Results

Each dependent variable was submitted independently to 2 x 2 x 2 x 2 ANOVA using repeated measurements on the last three factors. The first factor corresponded to the two age groups used in the present study. The second factor was the target presentation time (50 ms vs. 500 ms). The third factor was the recall delay (100 ms vs. 10000 ms) whereas the fourth and final factor concerned the masking procedure (masked vs. no-masked). As in Experiment 1, the target location was not considered as an experimental factor. All significant main effects and interactions were further delineated using the Newman-Keuls technique ($p < .01$). None of the dependent variables was affected by age ($p > .14$; see Table 3). Mean results obtained for all dependent variables as a function of the target presentation time and of the recall delay are presented in Table 4.

Insert Tables 3 and 4

### Variable error

The ANOVA revealed significant main effects of the target presentation time, $F(1, 18) = 18.77$, and of the recall delay, $F(1, 18) = 27.97$. The main effect of the target presentation time indicated a larger variable error for the 50 ms than for the 500 ms target presentation time (24.09 mm vs. 20.21 mm, respectively). Moreover, as illustrated in Figure 5, introducing a mask following target extinction resulted in a significant increase in pointing variability for the 100 ms recall delay but not for the 10000 ms recall delay. This is supported by an interaction between the recall delays and the masking procedures, $F(1, 18) = 7.56$, $p = .013$.

Insert Figure 5 approximately here

### Constant error

The ANOVA only revealed a significant main effect of the recall delay, $F(1, 18) = 18.53$. As in Experiment 1, this effect indicates an overshoot of the target for the shorter recall delay (7.7 mm) and an undershoot of the target for the longer recall delay (-9.74 mm).

### Movement kinematics

Peak aiming velocity was significantly larger for the shorter than for the longer recall delay, $F(1, 18) = 24.53$ (412.7 mm/s vs. 365.7 mm/s, respectively). In addition, there was a trend, F (1, 18) = 7.57, p = .013, indicating that peak aiming velocity was larger for the 50 ms rather than the 500 ms target presentation time (398.8 mm/s vs. 379.6mm/s, respectively).

To evaluate the efficiency of the movement planning processes, we evaluated where the movement first impulse ended in relation to the target location. A negative value indicates that the movement first impulse ended short of the target, whereas a positive value would indicate that it overshot the target. The ANOVA computed on this dependent variable revealed a significant main effect of the recall delay, F (1, 18) = 14.7. Its breakdown reveals a smaller undershooting of the target location for the 100 ms recall delay than for the 10000 ms recall delay (-8.2 mm vs. –28.8 mm, respectively). These results are qualitatively very similar to what has been found for the constant error of aiming.

Movement time and the absolute duration of the acceleration phase were shorter for the 50 ms than for the 500 ms target presentation time (1042 ms vs. 1104 ms for movement time, and 398 ms vs. 420 ms for the absolute duration of the acceleration phase, respectively), Fs (1, 18) = 9.13 and 11.93, respectively. The absolute duration of the deceleration phase and the proportion of corrected trials were not affected significantly by any of the independent variables (p > .07), indicating that our main results were not affected by response correction processes.

### Supplementary analyses

Because it was surprising that the masking procedure had no significant impact on pointing peak velocity, we conducted a series of ANOVAs for which the order of presentation of the masked and of the unmasked trials was considered as an experimental factor. For movement peak velocity, the results of this analysis revealed that for participants who began the experiment in the no-masked condition, as in Experiment 1, peak velocity was lower for the 10000 ms recall delay than for the 100 ms recall delay. However, for the participants who began the experiment in the masked condition, no differences in peak velocity were found as a function of the recall delay, $\underline{F}(1, 16) = 7.84$, $\underline{p} = 0.012$. The results of interest are illustrated in Figure 6. None of the remaining dependent variables were affected by the presentation order of the masked and unmasked trials.

Insert Figure 6 approximately here

## Discussion

The main goal of the second experiment was to determine whether the low pointing variability and the high peak velocity noted in Experiment 1 when pointing movements were initiated shortly after target extinction revealed that participants controlled their movement on the basis of a target representation available in iconic memory. To reach our goal we used a masking procedure preventing iconic storage of the target location (Elliott et al., 1990; Sperling, 1960). In addition, we also wanted to determine whether aging would modify the maintenance of information related to target location in memory.

The results of the present experiment indicated that, for a short recall delay, introducing a mask immediately following target extinction resulted in an increase in pointing variability compared to a no mask condition. In addition, for the participants who began the experiment in the no mask condition, lower peak velocities were noted in the masked than in the no-masked conditions. Both these findings suggest that for movements initiated shortly after target extinction, participants speeded up execution of their movements to benefit from the information concerning target location that is available in iconic memory. On the contrary, when a long recall delay was used, the introduction of a mask following target extinction did not modify either pointing variability or movement peak velocity in comparison to a no mask condition. This last finding supports previous observations indicating that the target representation available following target extinction is of short duration (Elliott & Madalena, 1987; Elliott et al., 1990) and extends them by showing that participants used a movement strategy (movement velocity) which optimized the use of iconic information for movement control.

The fact that the masking procedure only influenced peak velocity for participants who began in the no mask condition is interesting. It suggests that participants in the present experiment tended to stick with the source of information available early in practice to ensure movement control. Because the masking procedure prevented target location to be stored in iconic memory, participants who began the experiment in this condition had no reason to speed up their movements when a short recall delay was used and kept the same strategy even when target extinction was no longer followed by a mask.

Consistent with the results of Experiment 1, we found that participants overshot the location of the target more for the shorter than for the longer recall delays, suggesting a contraction of the workspace with an increase in the recall delay. The same observation was also made when we evaluated the distance covered by the movement first impulse, which is thought to represent the raw output of the motor planning stage. Thus, it appears that the biases found in the present study were largely, if not solely, related to movement planning processes. In addition, we did not find any difference in performance between the older and the younger participants, and this for both the masked and the no-masked procedures. This suggests that encoding of target location in memory, when one's goal is to accurately point towards it, is not affected by age.

## General Discussion

Performing an aiming movement towards a target that is no longer visible requires that its location, and eventually its physical characteristics, be kept in memory. The goal of the present study was to evaluate the effects of three factors thought to affect the quality of the memory representation of target location on pointing accuracy and variability: the target presentation time, the recall delay taking place between target extinction and movement initiation, and aging.

The first result of importance of the present study was the clear demonstration that movements initiated shortly ( < 1 s) after the extinction of the target were performed with a higher peak velocity and, nonetheless, were less variable that movements performed after a 10 s recall delay. Further, when a short recall delay was used, introducing a visual mask following target extinction resulted in an increase in pointing variability as well as in a decrease in movement peak velocity. However, when a long recall delay was used, none of the dependent variables were affected negatively by introduction of a mask following target extinction. This pattern of results indicates that pointing to a no longer visible target can be planned and/or controlled by information on the location of the target in iconic memory. This conclusion is well in line with previous results reported by Elliott and his colleagues (Elliott & Madalena, 1987; Elliott et al., 1990). In addition, the results of the present study extend previous conclusions by showing that iconic memory does not only favor pointing consistency, but that it dictates a movement strategy favoring higher peak movement velocity. In that regard, the fact that high peak movement velocity was associated with low pointing variability – a rare observation (see Meyer et al., 1982; Schmidt et al., 1979) – clearly indicates that higher peak movement velocities were used to benefit from the persistence of information in iconic memory related to target location.

When pointing with one's unseen hand to a remembered target, one has to translate into the appropriate motor commands the information about target information and the initial arm position. In such a condition, recent observations reported by McIntyre et al. (1998; see also Carrozzo et al., 1999; Soechting & Flanders, 1989a, b) suggest that the target would be first encoded in a viewer-centered frame of reference (based on retinal and extra-retinal cues) and then transformed in a body-centered frame of reference (arm or shoulder-centered; however see also Chieffi et al., 1999; Vindras & Viviani, 1998 for evidence of a hand-centered frame of reference). Our data suggest that the short-lived information about target location that is maintained in iconic memory can be used to update its egocentric representation in memory (viewer-centered or body-centered). In this view, the difference in the aiming constant error and variable error found between short and long recall delays in the present study would result from the decaying of this egocentric target representation over time, or of the resulting movement representation. In addition, the difference in constant error found between short and long recall delays could also result from a bias in the evaluation of the initial position of one's hand when visual information has been withdrawn for some time (Vindras et al., 1998; Wann & Ibrahim, 1992).

Finally, the results of the present study also indicated that increasing the recall delay had a similar effect for both the younger and the older participants. In both cases, it resulted in a significant increase in pointing variability. The fact that the increase in pointing variability was equivalent for both age groups suggests that older participants were not affected differently than their younger counterparts concerning the maintenance of target location in memory. This result differs from what has been found in previous work (Cherry & Park, 1989; Cherry et al., 1993; Hoyer, 1990; Smyth & Park, 1990; West, 1986) and is likely to have been caused by the nature of the experimental task used in these studies. In previous work, participants had to remember the location of numerous stimuli whereas in the present study there was a single stimulus. Thus, it could be that the effects of aging would only show with more demanding tasks requiring that numerous stimuli locations be kept in memory.

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Table 1. Mean (standard deviation) results obtained for younger and older adults for all dependent variables. Experiment 1.

| | | Dependent variables | | | | | |
|---|---|---|---|---|---|---|---|
| Group | Variable error (mm) | Constant error (mm) | Peak velocity (mm/s) | Movement time (ms) | Acceleration (ms) | Deceleration (ms) | Corrections (%) |
| Younger adults | 20.1 (6) | 11.7 (21.8) | 309 (82) | 1373 (410) | 473 (90) | 900 (366) | 65 (26) |
| Older adults | 26.7 (13) | 21.8 (64) | 377 (124) | 1184 (314) | 435 (83) | 749 (264) | 56 (32) |

Table 2. <u>Mean (standard deviation) results obtained for each dependent variable as a function of target presentation time and recall delays. Experiment 1</u>

| | Targets presentation time | |
|---|---|---|
| Recall delays | 50 ms | 500 ms |
| | Variable error (mm) | |
| 0 ms | 22.3 (4.8) | 19.4 (5.7) |
| 100 ms | 22.6 (5.4) | 17.6 (4.6) |
| 1000 ms | 21.8 (6) | 16.5 (2.9) |
| 10000 ms | 32.6 (8.7) | 22.4 (6.2) |
| | Constant error (mm) | |
| 0 ms | 42.5 (58.2) | 16 (51.3) |
| 100 ms | 39.2 (39.3) | 22.7 (49.2) |
| 1000 ms | 11.3 (55.9) | 6 (31.7) |
| 10000 ms | 5.5 (50.6) | -11.6 (38.2) |
| Peak velocity (mm/s) | | |
| 0 ms | 376 (123) | 322 (94) |
| 100 ms | 386 (119) | 343 (97) |
| 1000 ms | 353 (121) | 331 (95) |
| 10000 ms | 307 (108) | 302 (101) |
| | Movement time (ms) | |
| 0 ms | 1290 (324) | 1315 (400) |
| 100 ms | 1247 (327) | 1251 (292) |
| 1000 ms | 1247 (493) | 1279 (457) |
| 10000 ms | 1361 (396) | 1279 (353) |
| | Absolute acceleration (ms) | |
| 0 ms | 481 (92) | 468 (91) |
| 100 ms | 469 (79) | 463 (63) |
| 1000 ms | 448 (82) | 447 (68) |
| 10000 ms | 496 (101) | 368 (79) |

Table 2. Continued

| | Absolute deceleration (ms) | |
|---|---|---|
| 0 ms | 808 (268) | 847 (329) |
| 100 ms | 778 (258) | 786 (253) |
| 1000 ms | 800 (437) | 832 (407) |
| 10000 ms | 865 (323) | 912 (351) |

| | Proportions of trial with corrections (%) | |
|---|---|---|
| 0 ms | 59 (27) | 65 (31) |
| 100 ms | 54 (30) | 59 (29) |
| 1000 ms | 54 (32) | 60 (33) |
| 10000 ms | 69 (26) | 64 (27) |

Table 3. Mean (standard deviation) results obtained for younger and older adults for all dependent variables. Experiment 2.

| | Dependent variables | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Group | Constant error (mm) | CE prior correction | Variable error (mm) | Peak velocity (mm/s) | Movement time (ms) | Acceleration (ms) | Deceleration (ms) | Corrections (%) |
| Younger adults | 1.2 (3.1) | -22.9 (35.5) | 23 (7.6) | 359 (95.6) | 1167 (316) | 429 (88) | 738 (250) | 54.6 (31.7) |
| Older adults | -0.3 (4.3) | -14.2 (44.5) | 21.3 (9.8) | 419 (112) | 978 (211) | 389 (57) | 589 (180) | 40.1 (27.7) |

Table 4. Mean (standard deviation) of for each dependent variable as a function of masking procedure, target presentation time and of recall delay. Experiment 2.

| | Target presentation time : 50 ms | | Target presentation time : 500 ms | |
|---|---|---|---|---|
| Recall delays | Without mask | With mask | Without mask | With mask |
| | | Variable error (mm) | | |
| 100 ms | 19.2 (6.3) | 23.6 (10.9) | 15.5 (3.3) | 19.9 (9.4) |
| 10000 ms | 28.1 (11.7) | 25.5 (5.7) | 24.5 (7.9) | 21 (5.7) |
| | | Constant error (mm) | | |
| 100 ms | 12.1 (40.9) | 7.9 (37.6) | -6.8 (41.8) | 4 (35) |
| 10000 ms | -11.8 (34.3) | -10.8 (40) | -10.7 (38) | -5.6 (30.5) |
| | | Constant error prior correction (mm) | | |
| 100 ms | -3.3 (46) | -4.2 (36.9) | -8.9 (45.5) | -16.4 (31.8) |
| 10000 ms | -30.1 (38) | -27.4 (43.4) | -32.2 (41) | -25.8 (32.8) |
| | | Peak velocity (mm/s) | | |
| 100 ms | 426 (110) | 430 (105) | 403 (107) | 392 (100) |
| 10000 ms | 368 (104) | 371 (120) | 364 (115) | 359 (93) |
| | | Movement time (ms) | | |
| 100 ms | 1073 (280) | 999 (217) | 1086 (307) | 1105 (302) |
| 10000 ms | 1047 (291) | 1047 (234) | 1116 (362) | 1108 (284) |
| | | Absolute acceleration (ms) | | |
| 100 ms | 393 (62) | 386 (48) | 421 (97) | 409 (64) |
| 10000 ms | 409 (76) | 405 (62) | 419 (89) | 432 (100) |
| | | Absolute deceleration (ms) | | |
| 100 ms | 680 (237) | 614 (180) | 665 (237) | 696 (263) |
| 10000 ms | 638 (238) | 642 (194) | 696 (286) | 676 (211) |

Table 4. Continued

| | | Proportions of trial with corrections (%) | | |
|---|---|---|---|---|
| 100 ms | 47 (28) | 38 (32) | 47 (30) | 49 (33) |
| 10000 ms | 47 (31) | 49 (30) | 52 (33) | 50 (30) |

# Footnotes

[1] Besides transformation errors of the location of the target from an allocentric to an egocentric frame of reference, it has also been shown that part of the increase in error occurring when one points with his or her unseen hand towards a visual target is caused by an incorrect estimation of the position of their hand prior to movement initiation (Ghilardi, Gordon, & Ghez, 1995; Vindras & Viviani, 1998).

[2] Elliott and Calvert (1992) had participants aim at a target that was visible or remembered. They used a reaction time paradigm and for the remembered target conditions, withdrew vision at movement initiation, at the presentation of the reaction signal, or two seconds prior to presentation of the target signal. Thus, for the remembered target conditions, target presentation time decreased going from one condition to the other. However, there was a concomitant increase in recall delay, that is the delay between visual occlusion and movement initiation. Therefore, it is not clear whether the increase in aiming error found in that study when going from one condition to the other was caused by a modification in target presentation time and/or a modification in the recall delay.

[3] However, there was a trend for the older participants to have a higher variable error of aiming than the younger participants (26.7 mm vs. 20.1 mm, respectively), $\underline{F}$ (1, 17) = 5.03, $\underline{p}$ = .04).

[4] In fact, Lovelace and Aikens (1990) proposed that older individuals were less accurate than younger ones. However, their data did not indicate any significant difference between the two age-groups. In addition, the dependent variable used in that

study was not clearly defined. Presumably, it was the absolute error of aiming which confounds pointing accuracy and pointing variability (see Schmidt & Lee, 1999).

## Authors' Note

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## Figures captions

Figure 1. Apparatus. For clarity, the cursor moved by the participants and the targets are presented in black and the screen is presented in white.

Figure 2. Variable error of pointing as a function of the recall delays and of the target presentation times. Note the increase in variability when going from the three shorter recall delays to the 10,000 ms recall delay.

Figure 3. Variable error and peak velocity of pointing as a function of the recall delays.

Figure 4. Time course of the events taking place in Experiment 2. The target was presented for either 50 or 500 ms and was followed by the presentation of a visual mask for 100 ms. Recall delays were of either 100 ms or 10000 ms. The numbers presented at the left of each line of events indicate target presentation time and recall delay in ms, respectively.

Figure 5. Variable error of pointing as a function of the recall delays and of the masking procedure.

Figure 6. Peak velocity of pointing as a function of the order of presentation of the mask and of the no-mask conditions.

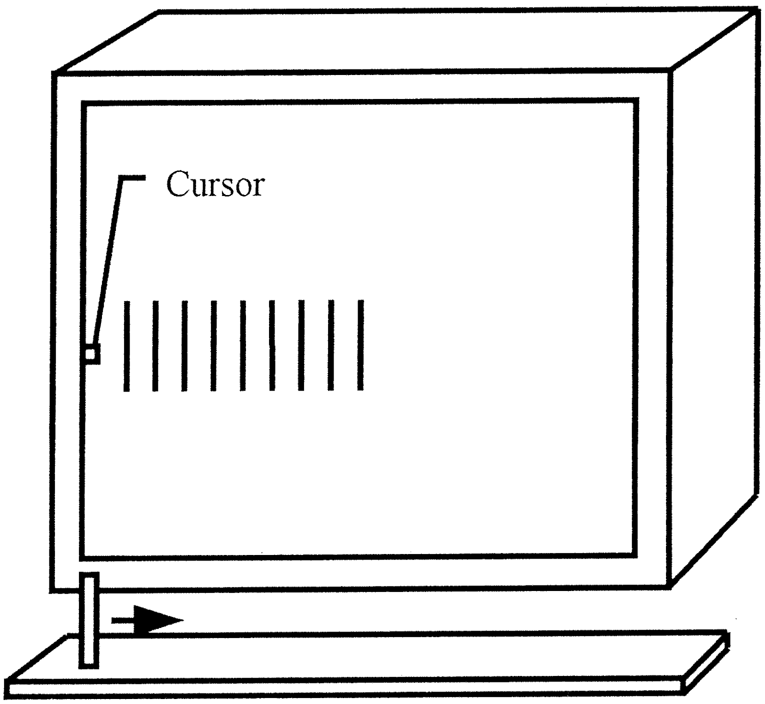


Figure 1

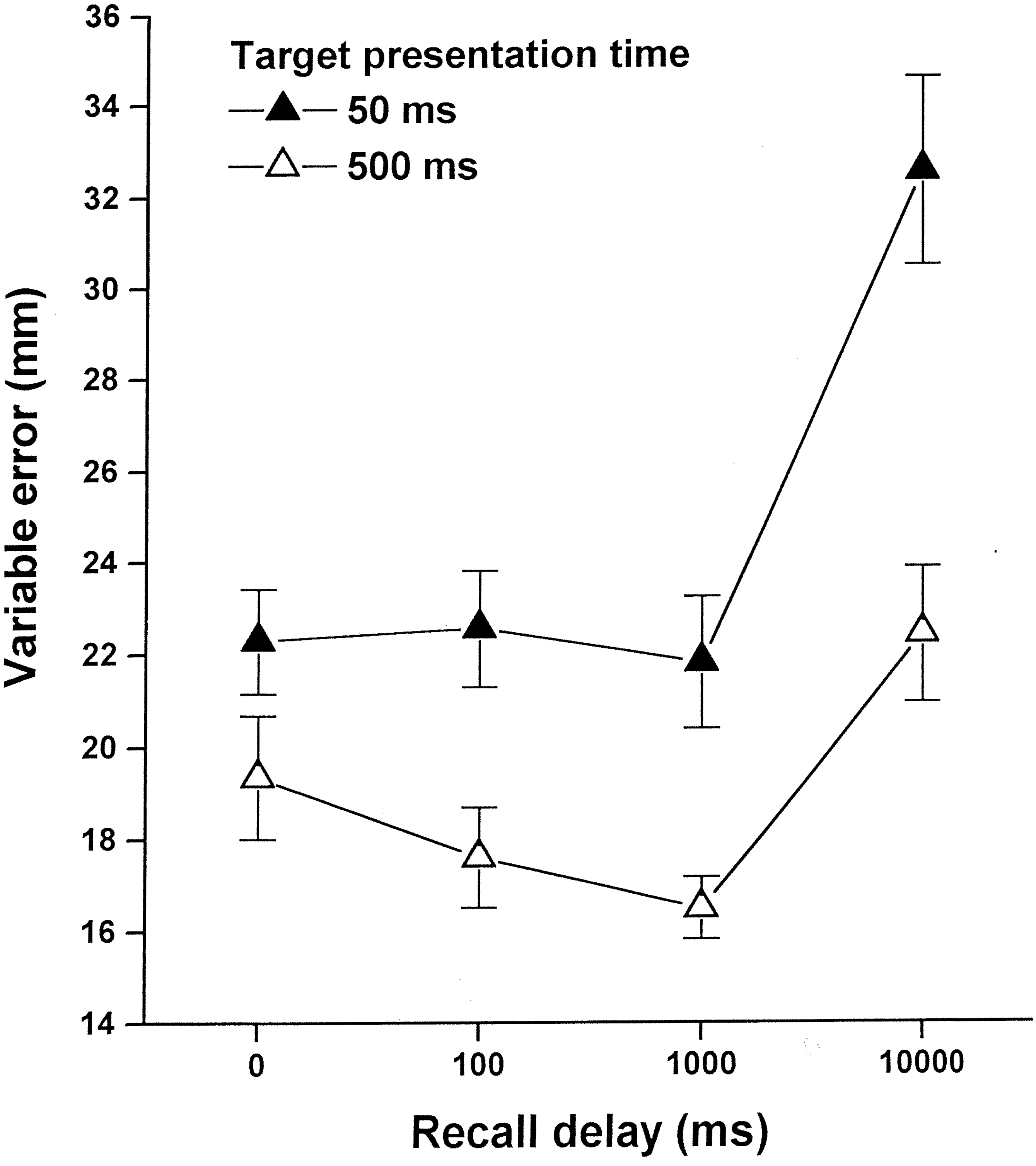
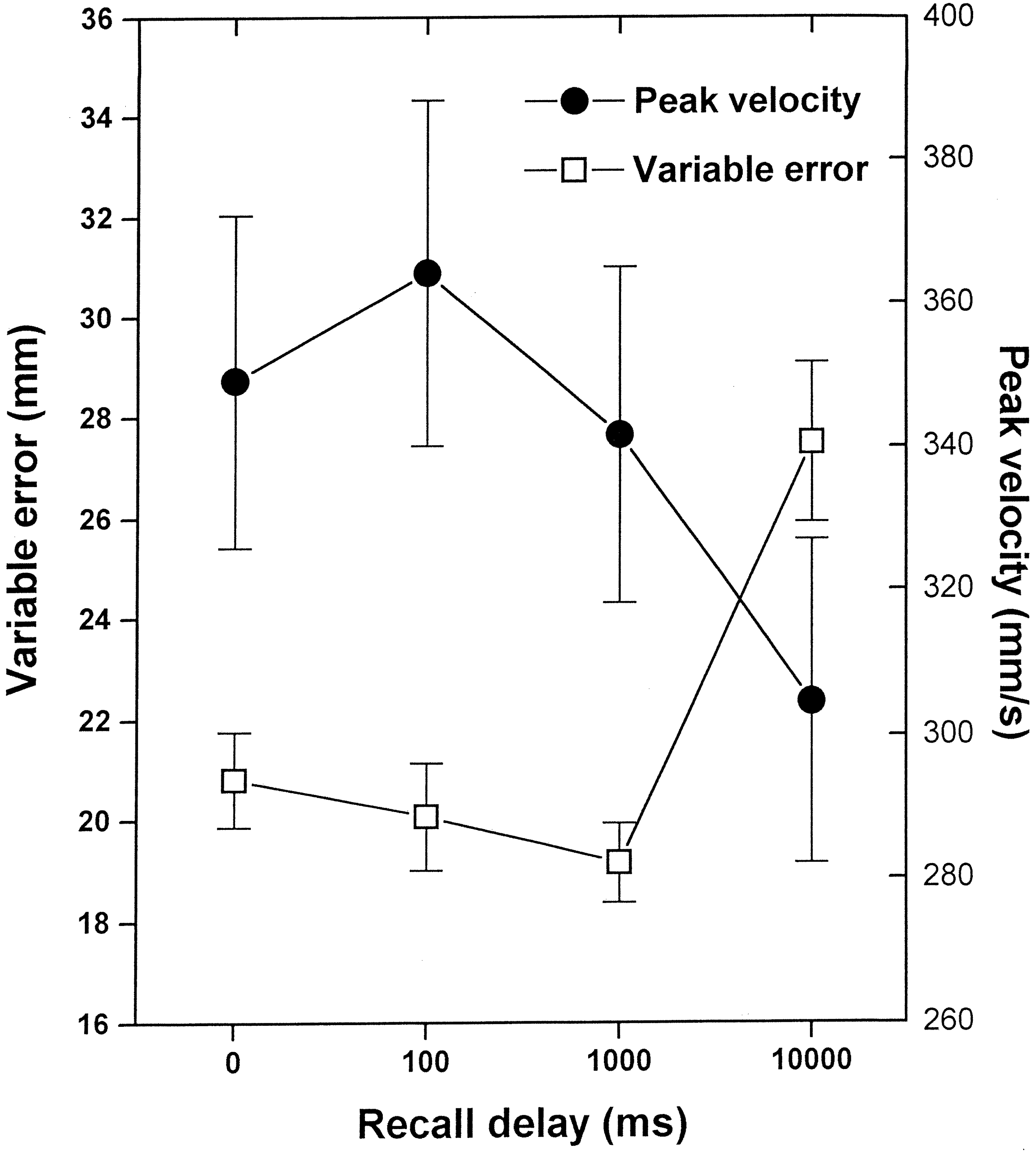
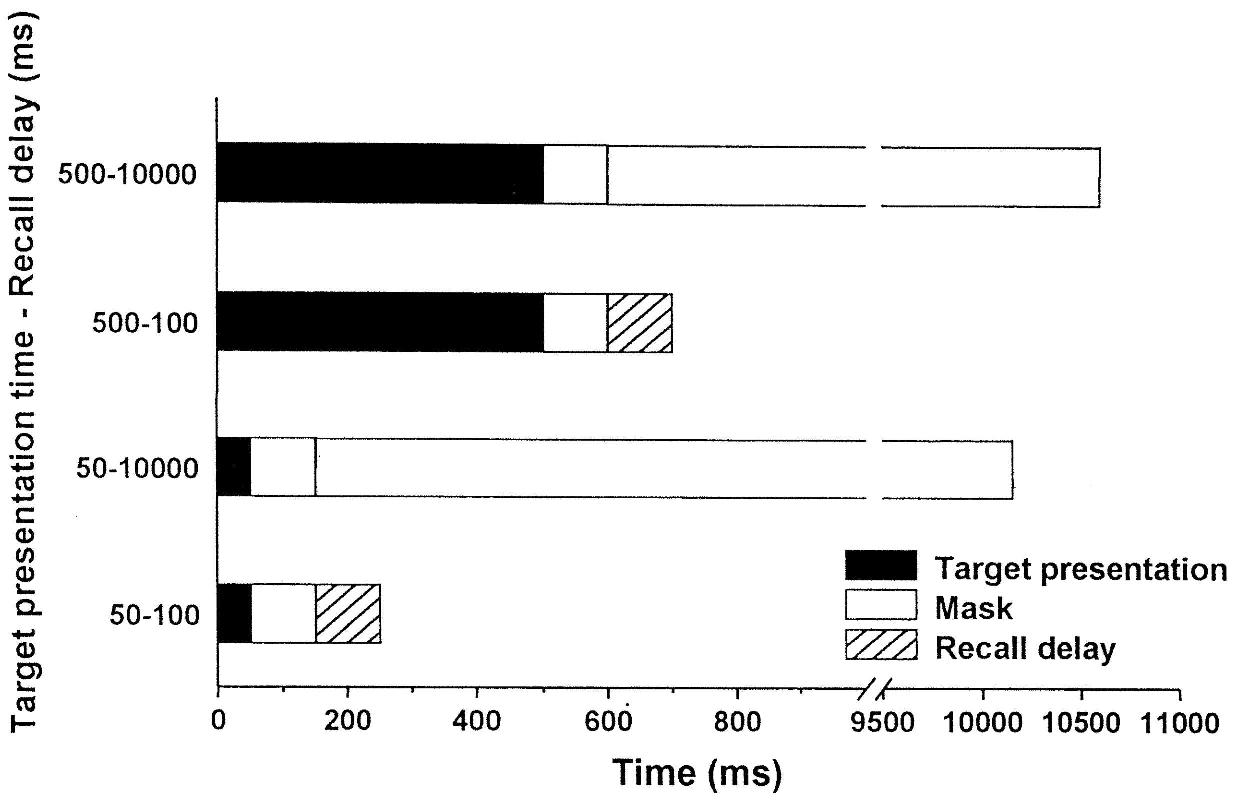

Target presentation time
50 ms
500 ms
Variable error (mm)
36
34
32
30
28
26
24
22
20
18
16
14
0
100
1000
10000
Recall delay (ms)

Figure 2


Peak velocity
Variable error
Variable error (mm)
Peak velocity (mm/s)
Recall delay (ms)
36
34
32
30
28
26
24
22
20
18
16
400
380
360
340
320
300
280
260
0
100
1000
10000


Target presentation time - Recall delay (ms)
500-10000
500-100
50-10000
50-100
Target presentation
Mask
Recall delay
0
200
400
600
800
9500
10000
10500
11000
Time (ms)

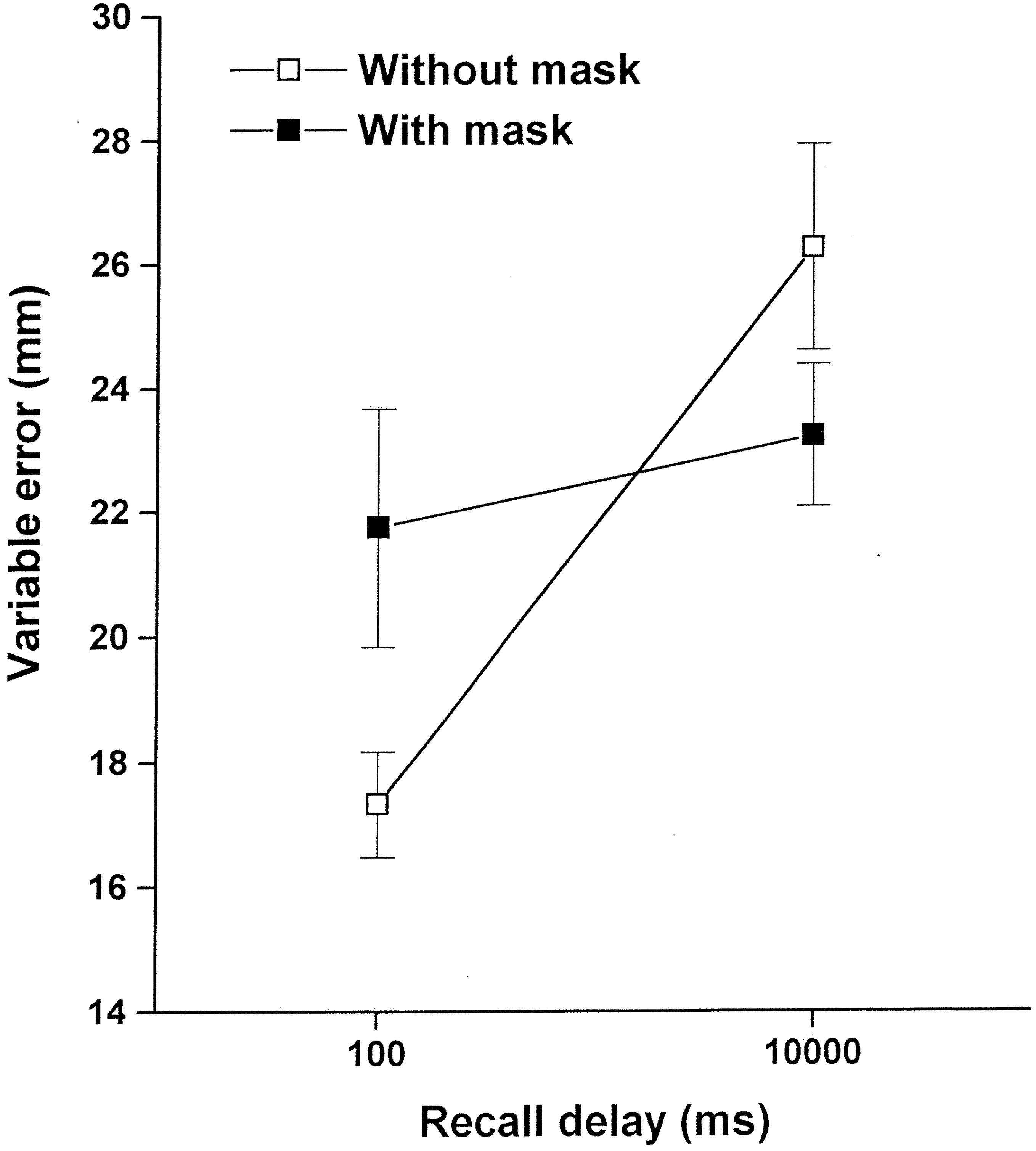

Without mask
With mask
Variable error (mm)
30
28
26
24
22
20
18
16
14
100
10000
Recall delay (ms)

Figure 5

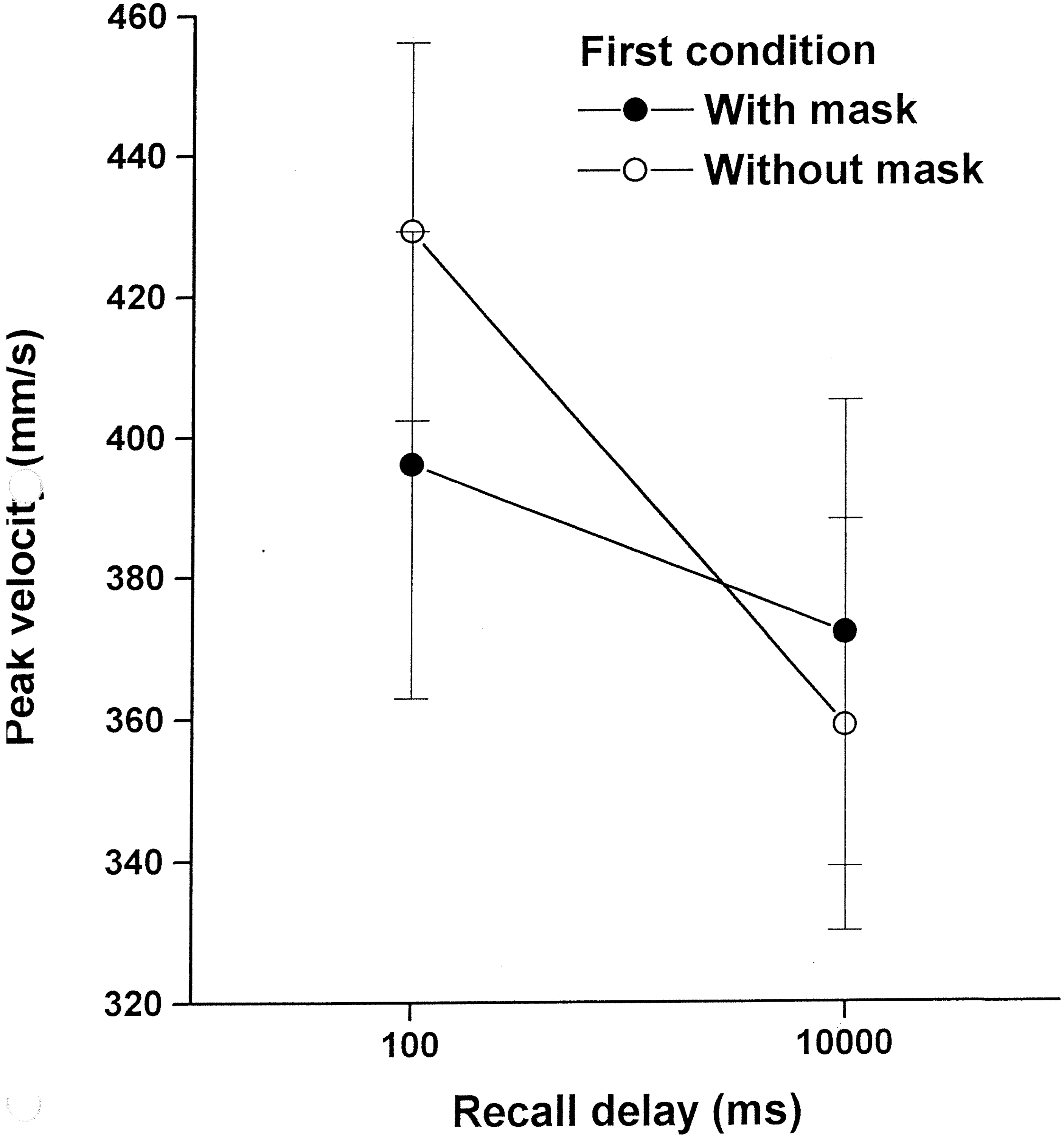

First condition
With mask
Without mask
Peak velocity (mm/s)
460
440
420
400
380
360
340
320
100
10000
Recall delay (ms)

Figure 6

# CHAPITRE 3

## ARTICLE 2

# Distance Effect in a Manual Aiming Task to Remembered Targets :

## A Test of Three Hypotheses

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Running title: Manual aiming to remembered targets

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## Abstract

It has been noted that manual aiming error and variability when pointing to remembered targets increase as a function of target eccentricity. In the present study we evaluated which one of three hypotheses (target localization, motor, or movement duration) best explains this ‘distance effect’. In Experiment 1, older and younger participants aimed with their unseen hand at the remembered location of targets distributed between 129 mm and 309 mm from the starting base. Target presentation time was of either 50 ms or 500 ms and aiming movements could be initiated following either a 100 ms or a 10,000 ms recall delay. Participants had either no constraints concerning movement time or were asked to reach the near target in a longer movement time than the farther targets. The results revealed a significant distance effect when no time constraints were imposed but showed a significantly reversed distance effect when the instructions were to reach the near targets in a longer movement time than the far targets. The same results were obtained regardless of target presentation time, recall delay, or age of the participants. These results supported a movement duration interpretation of the distance effect. In Experiment 2, a distance effect was replicated when pointing with one’s unseen hand towards a remembered target but did not take place when pointing to visible targets. Taken together these results suggest that movement execution interferes with this stored egocentric target representation.

Key words: Aiming, reference frame, memory, sensorimotor transformations, aging

# Distance Effect in a Manual Aiming Task to Remembered Targets :

## A Test of Three Hypotheses

Aiming movements towards visual targets are amongst the most frequently performed movements of our repertoire. These movements are performed in a variety of situations. They are most accurate when one's hand is visible throughout the movement towards a visible target (Proteau & Cournoyer, 1990; Elliott, Carson, Goodman, & Chua, 1991, Desmurget, Rossetti, Prablanc, Stelmach, & Jeannerod, 1995). They become less accurate when one's hand is not visible during movement execution, (Carrozzo, McIntyre, Zago, & Lacquaniti, 1999; Ghilardi, Gordon, & Ghez, 1995, see also Proteau, 1992 for a review) and become even less accurate when the target is no longer visible as movement unfolds (Adamovich, Berbinklit, Smetanin, Fookson, & Poizner, 1994 ; Darling & Miller, 1993; Lemay & Proteau 2001; McIntyre, Stratta, & Lacquaniti, 1998; Soechting & Flanders, 1989a, b).

Within the latter type of aiming movements, performance is dependent on a host of factors. The objective of the present study was to determine why the spatial error (Adamovich, Berkinblit, Fookson, & Poizner, 1998; see Figure 3a visual condition; Adam, Ketelaars, Kingma, & Hoek, 1995; Adam, Paas, Ekering, & van Loon, 1993) and/or spatial variability (Lemay & Proteau, 1998; Messier & Kalaska, 1997 ; Prablanc, Pélisson, & Goodale, 1986) of manual aiming movements to remembered targets increases as a function of an increase in movement amplitude. This decrease in aiming performance as a function of movement amplitude will be referred to as the 'distance effect'. It is important to mention that the distance effect does not simply illustrate the well known speed-accuracy trade-off that takes place between manual aiming accuracy/variability and movement time (Fitts, 1954; Meyer, Smith, & Wright, 1982; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). The effect is observed when participants were asked to reach the target at their own comfortable pace and were allowed to make discrete corrections to their movement until they were confident that it was accurate (Lemay & Proteau, 2001). Rather, there are at least three competing hypotheses that are more likely to explain the distance effect. The first hypothesis is motor in nature, the second one is linked to localization and perception of the target, whereas the third is linked to movement duration. In addition, because aging is likely to mediate the distance effect, potential aging effects will be considered in the presentation of these hypotheses.

### The motor hypothesis

The motor hypothesis is based on the common observation that when participants are asked to aim at the target at their own comfortable pace (Atkeson & Hollerbach, 1985; Berthier, Clifton, Gullapalli, McCall, & Robin, 1996; Messier & Kalaska, 1999) or as quickly and accurately as possible (Gordon, Ghilardi, Cooper, & Ghez, 1994; Gordon, Ghilardi, & Ghez, 1994), the peak velocity of manual aiming movements increases as a function of movement amplitude. As suggested by Prablanc et al. (1986), because aiming accuracy and variability to a particular target location (i.e., same movement amplitude) are negatively affected by an increase in peak movement velocity (Fitts, 1954; Meyer et al., 1982; Schmidt et al., 1979), the distance effect might simply reflect that longer movements are less accurate and/or more variable than shorter ones. However, in contradiction with the motor hypothesis, there is evidence that the variability of movements to remembered targets is not modified by movement velocity (Adamovich, Berkinblit, Fookson, & Poizner, 1999), with the exception of movements performed at maximal velocity that were found to be more variable than movements performed at lower velocities (Adamovich et al., 1994).

Concerning the effects of aging, it has been shown that decreasing movement time to a fixed target location resulted in larger increase in error for older than for younger adults (Welford, Norris, & Shock, 1969; see also Chaput & Proteau, 1996). Considering the observation that aiming peak velocity is larger for farther than for nearer targets, support for the motor hypothesis would be gained if the distance effect was found to be larger for older than for younger adults.

### The target localization/perception hypothesis

It has been suggested (Adam et al., 1995; Prablanc et al., 1986) that the distance effect might result from the fact that farther targets are usually detected in the periphery of a visual display and, thus, are not perceived as well as a target located near the center of the same display because: (a) the farther target is seen in visual periphery where the acuity of the visual system concerning the location of objects is relatively weak (Klein & Levi, 1987; Westheimer, 1982), and (b) the visual saccade required to foveate a farther target is performed at a very high velocity, resulting in an increase in its variability (Abrams, Meyer, & Kornblum, 1989). Thus, it could be argued that the poorer localization/perception of farther rather than closer targets might result in larger manual aiming error and variability, causing the distance effect. This explanation holds well for studies in which target presentation time was very short (Adam et al., 1993, 1995; Lemay & Proteau, 1998; Prablanc et al., 1986). However, a distance effect was also observed when participants aimed at the remembered location of the target but only after they had had enough time to foveate it prior to movement initiation. Specifically, the target was visible for 2 s in the Adamovich et al. (1998) study and for as long as the participant wanted in the Messier and Kalaska (1997; Task 1) study. Although the results of the last two studies argue against a target localization/perception explanation of the distance effect, it might be that the effect is mediated by a target localization/perception factor and that it would increase when the time allowed to participants to foveate the target decreases.

It has been shown that aging results in an increase in the time required to initiate a visual saccade towards a visual target by up to 100 ms (Morrow & Sharpe, 1993; Moschner & Baloh, 1994; Munoz, Broughton, Goldring, & Armstrong, 1998; Pratt, Abrams, & Chasteen, 1997; Warabi, Noda, & Kato, 1986). In addition, Moshner and Baloh (1994) has shown that peak saccade velocity to a target located at 30° of visual angle from a fixation point was decreased by as much as 71°/s for older participants in comparison to younger adults (see also Morrow & Sharpe, 1993; Munoz et al., 1998 for similar results). Both these effects of aging on the performance of ocular saccades suggest that target foveation is longer in older than in younger adults. Thus, if the distance effect is caused by target localization/perception, the presentation of the target for a short period of time should result in a larger distance effect for older than for younger participants.

### The movement duration hypothesis

Pointing with one's unseen hand to a remembered target requires that information about target information and initial arm position be translated into appropriate motor commands. In such a condition, recent observations reported by McIntyre et al. (1998; see also Carrozzo et al., 1999; McIntyre, Stratta, & Lacquaniti, 1998; Soechting & Flanders, 1989a, b;) suggest that the target location would be first encoded in a viewer-centered frame of reference (based on retinal and extra-retinal cues) and then transformed into a body-centered frame of reference (arm or shoulder-centered; however see also, Chieffi, Allport, & Woodin, 1999; Vindras & Viviani, 1998 for evidence of a hand-centered frame of reference).

Depending on the delay between disappearance of the target and movement completion, the stored location of the target might be available through different memory systems. When this delay is short (in the order of 1 s), target location might be available in a brief duration sensory memory store, such as iconic memory (Adam et al., 1995; Elliott & Calvert, 1992; Elliott & Madalena, 1987; Hanari, 1996; Lemay & Proteau, 2001). In this situation, it is plausible that the target is available in a viewer-centered frame of reference, because the participant has still access to a visual representation of the target as has first been shown by Sperling (1960). When longer delays elapse between target disappearance and movement completion, because the information available in iconic memory decays rapidly, it is likely that the location of the target used for movement planning and control is based on its representation in the visuo-spatial sketchpad (Baddeley & Hitch, 1974; Logie, 1995), a more durable memory, which codes the location of the target in a body-centered frame of reference (hand-centered, Chieffi et al.,1999). The larger errors found for farther than for nearer targets might result from this putative transition from a viewer-centered to a body-centered frame of reference (see

McIntyre et al., 1998 for confirming evidence), or by the simple passage of time as movement unfolds.

According to the movement duration hypothesis, aging should not modify the distance effect. This is so because Lemay and Proteau (2001) recently showed that older participants performed manual aiming movements to remembered targets as accurately and with no more variability than younger participants for both short (100 ms) and long recall delays (10,000 ms).

## Experiment 1

The first goal of the present study was to determine which one of the three hypotheses reviewed above better explains the distance effect. To reach our goal we had participants aim at remembered targets. For a first group (hereafter called 'control group'), the instructions were to aim at the target at a comfortable pace. We were expecting to observe longer movement times and higher peak movement velocities for farther than for nearer targets (Atkeson & Hollerbach, 1985; Gordon et al., 1994a, b; Messier & Kalaska, 1999). For a second group (hereafter called 'experimental group'), participants were asked to reach the nearer targets in a relatively long pre-determined movement time bandwidth (between 2 s and 5 s) but to reach the farther targets in a relatively short movement time (1 s).

If the distance effect is caused only by a target localization/perceptual factor, because the instruction given to the experimental group could not have any effect on target perception, we should observe a distance effect for both the control and the experimental groups. If motor processes cause the distance effect, asking participants in the experimental group to reach the farther targets in a shorter movement time than the nearer targets should increase peak velocity for the farther targets in comparison to the control group and result in a larger distance effect for the experimental than for the control group. However, if the movement duration hypothesis better explains the distance effect, this effect should be observed for the control group but <u>reversed</u> for the experimental group because the nearer targets are reached in a longer movement time than the farther targets.

We also manipulated the delay between target disappearance and movement initiation (i.e., a recall delay) and the time for which the target was visible. We used short (100 ms) and long (10000 ms) recall delays to determine whether the distance effect is mainly caused by the passage of time or whether it is linked with movement duration as suggested by the movement duration hypothesis. If the distance effect is caused by the passage of time between target disappearance and movement completion, aiming performance, at least for the control group, should suffer more from an increase of the recall delay from 100 ms to 10000 ms than from an increase in movement duration. On the contrary, if it is movement duration per se that causes the distance effect, an increase in movement duration would be more detrimental to aiming performance than an increase in the recall delay.

Increasing target presentation time increases the likelihood that target foveation be completed before the target has been extinguished. Thus, if target localization processes cause the distance effect, it should be smaller for the longer than for the shorter target presentation time. Also, because target presentation time does not influence movement time or movement peak velocity (Lemay & Proteau, 2001), increasing target presentation time should not influence the distance effect if either motor processes or movement duration cause this effect.

Finally, we wanted to determine whether aging would influence the distance effect. As proposed above, the motor and target localization hypotheses suggest a larger distance effect for older than for younger participants whereas the movement duration hypothesis does not suggest any modulation of this effect by age.

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## Method

### Participants

Twenty younger adults (M: 22.7 years old, SD : 3.49 years) and twenty older adults (M: 70.55 years old, SD: 4.64 years) took part in this study. All participants were self-declared right handed, had good upper limb mobility and did not have any visual deficit except those corrected by prescription lenses. The younger participants were all students in the Département de kinésiologie at the Université de Montréal. All older participants lived in their own residences and reported being in good health. All participants were paid for their time and were unaware of the purpose of the study.

### Tasks and apparatus

Participants aimed at one of nine possible targets presented on a computer screen (Mitshubishi Color Diamond Pro, 37 inches equipped with a Matrox Millenium II video card having a resolution of 1024 X 768 pixels). Specifically, participants held a pointer with their thumb and index finger and moved it on a near frictionless track located in front of the computer screen and parallel it. The track was located 50 mm in front of the screen (see Figure 1) and was located 1 cm below the lower extremity of the target. The task was very much like dragging one's finger on the screen from a fixed starting position to a target shown on the screen, however without touching it. A cardboard shield prevented the participants from viewing their upper limb or their pointer. All targets were white (on a black background), with a width of 3.2 mm and a height of 64.5 mm (sustaining a visual angle of 0.366° and 7.35°, respectively). The distance between the participant and the computer screen was 500 mm. The distance between each target was 22.5 mm. They were located at a minimum of 129 mm and at a maximum of 309 mm from a fixed starting base aligned with the left edge of the computer screen.

The pointer was connected to an optical encoder (U.S. DIGITAL, model S2-1024-NT, sampling rate of 500 HZ, spatial precision of 0.17 mm), sampled by a microcomputer. For the whole experiment, participants wore liquid crystal goggles (Plato Translucent Technologies), which changed from a transparent to a translucid state immediately after the presentation of the target, thus instantaneously (~ 3 ms) depriving participants of visual contact of the target and the apparatus in general.

Insert Figure 1 approximately here

## Procedure

Participants sat in front of the computer screen. They were asked to gaze at the screen before the beginning of each trial. We did not use a fixation point to prevent the possibility that visual persistence of this point could be confounded with that of the target. At the beginning of each trial, the participant had to hold the pointer between the thumb and the index finger of his or her non-dominant hand. Once the pointer was stabilized at the starting position, the target was presented on the computer screen and remained visible for either 50 ms or 500 ms. The target and all other visual cues disappeared from view when the goggles' lenses went from their transparent to their translucent state. Once the goggles were set in their translucent state, the participant was to wait for a delay of either 100 ms or 10,000 ms before initiating his or her movement towards the target. An auditory stimulus indicated when movement could start. The beginning of the pointing movement was defined as the moment at which the velocity of the pointer exceeded 3 cm/s whereas the end of the movement occurred when the velocity of the pointer decreased below 3 cm/s for at least 1000 ms. This procedure allowed participants to correct their movement if they so desired.

The experiment began with a practice block of 8 trials performed in normal vision (without goggles) and was followed by a second practice block of 8 trials performed with the goggles in their translucent state. The objective of the first block of practice was to familiarize participants with the pointing task, whereas the second block of practice was used to familiarize participants with the experimental procedures. For the control groups (one in each age group), participants were asked to reach the location of the target as accurately as possible and with no temporal constraints. For the experimental groups (again, one in each age group), participants were asked to complete their reaching movement in a movement time of between 2 s and 5 s for the four targets nearer to the starting base, and in a movement time of approximately 1s for the four targets located farther from the starting base. The middle target had to be reached in a movement time ranging between 2 s and 5s for one half of the trials and in a movement time of approximately 1s for the other half of the trials (the data collected for this target were not analyzed). The order of presentation of the two imposed movement times was randomized for each participant. Relatively long movement times were used for the nearer targets because we wanted to make sure that all movements to the nearer targets would take longer than all movements to the farther targets. For each block of practice, four trials were carried out for each one of four target presentation times. For each of these four trials, the targets were visible for 500 ms for the first trial and then the presentation time decreased to 300 ms, 150 ms and 50 ms for the next trials of practice. Practice trials were carried out on targets located at intermediate positions compared to the targets used in the experimental phase. During this practice phase, participants were informed of the spatial accuracy of their movement in cm (for example, "your movement ended 2 cm short of the target").

Following the practice phase, the participants performed 72 experimental trials. These trials were presented in four successive blocks (2 target presentation times x 2 recall delays) of 18 trials each. The order of presentation of the different blocks was randomized across participants. In each experimental block of trials, the participants carried out two trials towards each of the nine possible targets. The order of presentation of the targets was randomized within each block with the restriction that each target was presented once in each successive series of nine trials. Participants in the experimental group were informed prior to each trial of the target movement time for the upcoming trial. During both the practice and the experimental phases, trials for which the participants did not complete their movement within the imposed time bandwidth were repeated. An experimental session lasted approximately 30 minutes.

Dependent variables. The main dependent variables of the present study were the absolute constant error and the variable error of aiming. The first one is the absolute value of the mean aiming error found for each participant. It was favored over the constant error of aiming (signed mean aiming error), which is used to determine whether aiming movements show a bias (undershooting or overshooting of the target), because none of the hypotheses reviewed in the introduction to explain the distance effect predicts a particular aiming bias. The variable error of aiming is the within-participant standard deviation of the individual movement endpoints. In addition, because the motor hypothesis predicts that aiming performance would be related to it, we also analyzed the peak velocity of the aiming movement. To this end, the displacement data of the cursor over time were first smoothed using a fourth order recursive Butterworth filter with a cutting frequency of 10 Hz. The smoothed data were then numerically differentiated once using a central finite technique to obtain the velocity profile of the aiming movement. Movement peak velocity was determined from this profile with an interactive software program. Movement initiation was defined as the moment at which the velocity of the pointer exceeded 3 cm/s whereas movement completion occurred when the velocity of the pointer decreased below 3 cm/s for at least 1000 ms.

Statistical analyses. To reach our first goal the data of the absolute constant error, of the variable error, and of the movement peak velocity were submitted to a 2 x 2 x 2 x 2 x 2 MANOVA using repeated measurements on the last three factors. The first factor corresponded to the two groups (experimental vs. control). The second factor corresponded to the two age groups used in the present study (younger vs. older adults). The third factor was the target presentation time (50 ms vs. 500 ms). The fourth factor was the delay between occlusion of the target and movement initiation (i.e., recall delay:100 ms vs. 10,000 ms), and the last factor concerned the target location. The results obtained for the three nearer and for the three farther targets in relation to the starting base were regrouped into two clusters (near targets vs. far targets). Significant effects ($p < .05$) were broken down by computing separate ANOVAs for each dependent variable. In all cases, significant main effects and interactions were further delineated using the Newman-Keuls technique ($p < .05$), corrected for the number of pairwise comparisons using the Bonferronni technique.

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## Results

The mean data (and standard deviation) obtained for all dependent and independent variables of the present experiment are presented in Table 1.

Insert Table 1 approximately here

### Movement time

As illustrated in Figure 2a (upper left panel), participants in the experimental group completed their movement to the near and far targets within the prescribed movement time bandwidth whereas, as expected, participants in the control group reached the near targets in a shorter movement time than the far targets. An ANOVA contrasting the five independent variables manipulated in the present study only revealed a significant Group x Target interaction, $F$ (1, 36) = 412.34, supporting the above observation.

Insert Figure 2 approximately here

The MANOVA computed on the three dependent variables revealed significant main effects of target, of target presentation time, and of the recall delay, Rao's R (3, 34) = 92.93, 4.19, and 11.29, respectively. In addition, the MANOVA revealed a significant

Group x Target interaction as well as a significant Group x Recall delay interaction, Rao's R (3, 34) = 50.72 and 3.90, respectively.

### Absolute constant error of aiming[3]

The Group x Target interaction was significant for this dependent variable, F (1, 36) = 17.81. It is illustrated in Figure 2 (lower left panel). The breakdown of this interaction revealed a significant distance effect for the control group, that is, a larger aiming error for the farther than for the nearer targets, and a significant but reversed distance effect for the experimental group, indicating a larger aiming error for the nearer than for the farther targets. The main effect of the recall delay, F (1, 36) = 4.8, was also significant, indicating a larger error for the 10000 ms recall delay than for the 100 ms recall delay (41.2 mm vs. 35 mm). For the control group, its worth noting that the passage of time per se (10000 recall delay minus 100 m recall delay) resulted in an increase in error of approximately 5.9 mm whereas, regardless of the recall delay, there was an increase in error of approximately 15 mm when going from the near to the far targets.

### Variable error of aiming

Again, the Group x Target interaction was significant for this dependent variable, F (1, 36) = 59.31. Its breakdown revealed a significant distance effect for the control group (larger variable error for the farther than for the nearer targets) and a significant but reversed distance effect for the experimental group (see Figure 2, upper right panel). Main effects of the target presentation time, F (1, 36) = 5.93 and of the recall delay, F (1,

36) = 9.24, were also significant. The first effect indicates a larger variable error for the shorter than for the longer target presentation time (27.4 mm vs. 24.0 mm), suggesting that increasing target presentation time permitted a better perception of target location. The second effect revealed a larger variable error for the longer than for the shorter recall delays (27.9 mm vs. 23.5 mm). This indicates that the information stored in memory concerning target location became less reliable as time went by (Carrozzo et al., 1999 ; Chieffi et al., 1999 ; Elliott & Madalena, 1987). However, for the control group and regardless of the recall delay, the simple passage of time had a smaller effect on variable error (3.6 mm) than movement duration (5.85 mm).

Movement peak velocity

The Group x Target interaction was also significant for this dependent variable, F (1, 36) = 85.69. This interaction is illustrated in Figure 2 (lower right panel). Its breakdown indicates that for both the control and the experimental groups, peak velocity was significantly higher for the farther than for the nearer targets. However, this increase in peak velocity was significantly more pronounced for the experimental than for the control group. This interaction was to be expected considering the movement time target bandwidth used for the experimental group. The Group x Recall delay interaction was also significant, F (1, 36) = 10.74. Its breakdown revealed for the control group a significantly higher peak velocity for the shorter than for the longer recall delay (370 mm/s vs. 301 mm/s). No effect of the recall delay was observed for the experimental

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[3] The constant error data showed that the control group undershot both the near and the far targets (-8.4 mm vs.-3.2 mm, respectively) whereas the experimental group undershot the near targets (-19.2 mm) but overshot the far targets (12.5 mm).

group (401 mm/s and 397 mm/s, respectively). The higher velocity found for the control group for the 100 ms recall delay suggests that participants might have increased the velocity of their movement to benefit from the information available in iconic memory to control their ongoing movement (see Lemay & Proteau, 2001 for similar findings). However, it is likely that the instruction given to the experimental group concerning movement time homogenized the aiming movements, which would explain why the recall delay did not influence peak velocity for this group. Finally, peak velocity was higher for the shorter (375 mm/s) than for the longer target presentation time (362 mm/s), F (1, 36) = 4.56.

## Discussion

The major goal of this experiment was to determine which one of a target localization, a motor, or a movement duration hypothesis better explains why aiming performance to remembered targets has been found to be a function of movement amplitude. The first major observation of the present study was that the distance effect was replicated for the control group because both the absolute constant error and the variable error of pointing were larger for the farther than for the nearer targets.

If the distance effect had been caused by poor target localization/perception, the distance effect should have taken place for both the control and the experimental groups, but nonexistent, or at least less pronounced, for a condition permitting better perception of the target. Increasing target presentation time from 50 ms to 500 ms resulted in a significant decrease in variable error of aiming suggesting that, indeed, it permitted better perception of the target (Adam et al., 1995; Lemay & Proteau, 2001). However, increasing target presentation time did not modify the distance effect. The above finding, the reversal of the distance effect for the experimental group, and previous results indicating the presence of a distance effect even when long target presentation times were used (Adamovich et al., 1998; Messier & Kalaska, 1997) indicate that a target localization explanation of the distance effect is not viable, neither as the main contributor nor as a modulator of the distance effect.

The motor explanation of the distance effect suggested that it resulted from higher peak velocities for aiming movements to farther rather than to nearer targets which, in turn, would have resulted in larger aiming error and variability. Considering that the farther targets were reached with a higher peak aiming velocity for the experimental than for the control group, this hypothesis would have been supported if a larger distance effect had been observed for the experimental than for the control group. This was clearly not the case. In fact, the results showed just the opposite.

The results suggest rather, that the distance effect is caused by movement duration. Numerous aspects of the results support this position. The first and most convincing support for our conclusion is that the distance effect was significantly reversed when participants were asked to reach the nearer targets in a longer movement time than the farther targets. The fact that larger pointing error and variability were found for the experimental group for movements of small amplitude (i.e, the nearer targets) that were reached in a long movement time indicated that it is movement duration not movement amplitude that causes the distance effect. The second line of evidence supporting the movement duration hypothesis comes from the observation that the difference in aiming accuracy and variability between the control and the experimental groups was larger for the nearer than for the farther targets (see Figure 2). This observation fits well with the movement duration hypothesis because the difference in movement time between the two groups was much larger for the nearer than for the farther targets. Note that this observation is opposite to what should have been observed according to the motor hypothesis whereas no difference should have been observed according to the target localization hypothesis. The last line of support comes from the fact that older participants behave exactly as their younger counterparts. This result supports the movement duration hypothesis because Lemay and Proteau (2001) recently showed that older and younger adults were similarly affected by an increase of the recall delay. Taken together, the results of the present study and those of Lemay and Proteau (2001) suggest that older adults are as capable as younger ones of retaining target location in memory. However, because this last line of support for the movement duration hypothesis is based on an absence of difference between the two age-groups, it should be considered with more caution.

The results also gave indication that the distance effect is not caused by the passage of time per se but that it is related to the duration of the ongoing movement. This position is supported by the observation that for the control group an increase in movement of approximately 300 ms when going from the near to the far targets resulted in nearly twice the increase in absolute constant error and variable error than that noted between recall delays of 100 ms and 10000 ms. This observation is important. It suggests that movement execution might interfere with the maintenance of target location in memory.

Finally, there was one aspect of the results of the present experiment that was unexpected. Considering that older participants have been shown to need more time than younger adults to foveate a target suddenly presented on a visual display (Morrow & Sharpe, 1993; Moschner & Baloh, 1994; Munoz et al., 1998; Pratt et al.,1997; Warabi et al., 1986), it was somewhat surprising that aiming performance was not affected by aging, especially for the shorter target presentation time. However, it should be remembered that we did not use a visual fixation point in the present study because it could have interfered with storage of the target location in memory. Thus, it is likely that the participants' gaze was directed near the middle of the visual display. By doing so, the extreme targets were located at 10.2° of visual angle relative to the center of the display, that is, in central vision, which might have reduced the difference in the time required to foveate the target between younger and older participants to a negligible delay.

## Experiment 2

One goal of the present experiment was to ascertain whether the distance effect occurs because movement execution interferes with the stored location of the target in memory. This proposition would be supported if a significantly larger distance effect was observed when pointing towards remembered targets than when pointing towards visible targets. Although there is some evidence available to that effect (Prablanc et al., 1986), some confirmation is warranted. Because target presentation times, recall delay and age of the participants did not modulate the distance effect in Experiment 1, these factors were not included in the present experiment.

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## Method

### Participants

Ten students in the Département de kinésiologie at the Université de Montréal, none of whom had participated in Experiment 1, took part in this experiment, (M = 26.7 years old, SD = 8.27 years). All participants were self-declared right handed, were paid for their time and were unaware of the purpose of the study.

### Task, apparatus, and procedures

The task and apparatus were similar to those used in Experiment 1. The procedures were also similar to those used in Experiment 1 for the control group (i.e., no time constraints) but with a few exceptions. Participants completed 99 trials to remembered targets and also 99 trials to visible targets. The order of presentation of these two conditions of target visibility was counterbalanced across participants. When the target was not visible during movement execution, target presentation time was of 500 ms and the recall delay was of 100 ms for all trials. For both conditions of target visibility, the first 9 trials (1 trial per target) were considered as familiarization. Participants were informed of the accuracy of their movement following each one of these trials. For the remaining 90 trials, the order of presentation of the different targets was randomized with the restriction that each target was used once in every successive block of 9 trials. No knowledge of results was provided for these trials.

Dependent variables and statistical analyses. The dependent variables were the movement time, the absolute constant error of aiming, the variable error of aiming, and the movement peak velocity. They were submitted to a 2 x 2 MANOVA using repeated measurements on the two factors. The first factor was the condition of target visibility (visible vs. not visible), whereas the second factor concerned the target location, as defined in Experiment 1. The results of the MANOVA were broken down as described in Experiment 1. Data from one participant were withdrawn from all analyses because his or her results concerning the variable error of aiming differed by more than two standard deviations from the group mean.

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## Results

The mean data (and standard deviation) obtained for all dependent and independent variables of the present experiment are presented in Table 2.

Insert Table 2 approximately here

The results of the MANOVA revealed significant main effects of target visibility and of target location, as well as a significant interaction between these two factors, Rao's R (4, 5) = 6.6, 66.0, and 4.8 ($p = .055$), respectively. None of these effects were found significant for the absolute constant error of aiming[4]. However, as illustrated in Figure 3 (lower panel) when the target was visible, aiming error was somewhat smaller for the far than for the near targets. The opposite was observed when the target was not visible.

### Movement time

The ANOVA revealed that participants needed more time to complete their aiming movement for the far than for the near targets, $F$ (1, 8) = 41.89. In addition, movement time was significantly longer when the target was visible than when it was not, F (1, 8) = 11.11. The data of interest are presented in Table 2.

Insert Figure 3 approximately here

Variable error

The ANOVA revealed a significant main effect of Target , F (1, 8) = 7.59 as well as a significant Target x Target visibility interaction, F (1, 8) = 8.06. This interaction is illustrated in the upper panel of Figure 3. Its breakdown showed that a significant distance effect took place when the target was not visible; variable error was significantly larger for the far rather than for the near targets. On the contrary, when the target was visible, variable error is slightly smaller (not significant) for the far than for the near targets. This trend is opposite to the distance effect.

Movement peak velocity

The ANOVA revealed significant main effects of Target visibility and of Target, F (1, 8) = 8.47 and 57.5, respectively. The first effect indicates a higher peak velocity when aiming at remembered rather than at visible targets whereas the second effect indicates a higher peak velocity for the far than for the near targets. The results of interest are presented in Table 2.

Supplementary analyses

The results of both Experiment 1 and the present experiment suggest that the distance effect is caused by the decay of the remembered target representation as a function of movement duration. If this is the case, we should be able to observe that

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[4] The constant error data showed that near targets were undershot whereas far targets were slightly overshot (-13.8 mm vs. 4.7 mm).

longer movement times to similar target locations are resulting in an increase in pointing variability, and perhaps also in pointing accuracy, in comparison to shorter movement times. To test this prediction, we ordered the movement times of each participant from the shortest to the longest. Movement times and their corresponding target location were averaged over 18 blocks of five trials each. A variable error and an absolute constant error of aiming were then computed for each block. For the first twelve blocks, there was a concomitant increase in movement time and mean target distance (Pearson's coefficient of correlation = 0.98). Thus, it would not be possible to determine whether an eventual increase in pointing error and/or variability is linked to movement distance or to movement duration. However, for the 6 blocks associated with the longer movement times, participants aimed approximately at the same target location (fluctuated between 235 mm and 261 mm) but in different movement times (Pearson's coefficient of correlation = 0.51). The results of interest are presented in Figure 4. For the participants who aimed at a remembered target location, an increase in movement time from 1621 ms to 1968 ms resulted in gradual increase in pointing variability going from 19.1 mm to 26.6 mm (Pearson's coefficient of correlation = 0.99), whereas no such gradual increase in pointing variability as a function of an increase in movement time can be seen for participants who aimed at visible targets (Pearson's coefficient of correlation = 0.22). The absolute constant error did not fluctuate as a function of movement time, regardless of whether or not the target was visible.

Insert Figure 4 approximately here

## Discussion

The results of the present experiment are straightforward. A distance effect was obtained for the variable error when aiming to remembered targets whereas this was not the case when the targets were visible. The lack of significant difference in aiming accuracy and variability between the near and the far targets when the target was visible cannot be accounted for by a lack of statistical power in the present experiment. First of all our conclusion is based on a significant interaction. Secondly, when the targets were visible, aiming performance to the farther targets tended to be better, not poorer, than that to the nearer targets.

The most important aspect of these results is that the distance effect found in Experiment 1 for a short recall delay was replicated, although only for the variable error of aiming. Finding a distance effect when pointing to remembered targets and not when pointing to visible targets indicates that the distance effect has to do with the keeping of the target location in memory. Further, the results of the supplementary analysis supported our proposition that the distance effect is related to movement duration, not movement extent. Finally, contrary to Experiment 1, we did not find a distance effect for the absolute constant error of aiming. A possible explanation of these conflicting results might be that, for the combination of target presentation time and recall delay used in Experiment 2, a ceiling had been reached for this dependent variable. Specifically, in Experiment 2, mean movement time to the near remembered target was of 1372 ms for an absolute constant error of 19.2 mm. For the same experimental condition in Experiment 1 (young participants, target presentation time of 500 ms and recall delay of 100 ms) mean movement time was of 1334 ms <u>but for the farther targets</u>. It resulted in a mean absolute constant error of 20.8 mm. Thus it might be that the absolute constant error had reached a ceiling at a movement time of approximately 1400 ms, and would explain why absolute constant error did not show a distance effect in Experiment 2. This interpretation of the conflicting results is speculative but coherent with previous propositions suggesting that variable error and constant error do not provide a window on the same processes (Carrozzo et al., 1999; Guay, 1986; Guay & Hall, 1984; McIntyre et al., 1997; Soechting & Flanders, 1989a, b).

## General Discussion

The main goal of the present study was to determine which of a target localization/perception, a motor, or a movement duration hypothesis better explains the observation that pointing movements to remembered targets are less accurate and more variable with an increase in movement amplitude. The results of Experiment 1 supported previous observations suggesting that the target localization (Adamovich et al., 1998 ; Messier & Kalaska, 1997) and the motor (Adamovich et al., 1994, 1999) explanations of the distance effect were unlikely, but supported a movement duration interpretation of this effect. Further, the fact that we found a distance effect after both short and long recall delays suggests that it has a single cause, regardless of the recall delays used in the present study.

### The distance effect

As indicated above, a distance effect took place when pointing to remembered targets, regardless of the recall delay, but did not take place when the target remained visible throughout movement execution. This pattern of results clearly indicates that the distance effect is related to the storage/recoding of target location in memory. Although the distance effect is related to target storage, this effect clearly does not result from the simple passage of time as movement progresses from near to far targets. This position is supported by what is perhaps the most striking result of the present study. In Experiment 1, the 300 ms increase in movement time noted when going from the near to the far targets had deleterious effects on aiming performance, after both a 100 ms or 10000 ms recall delay (i.e., the distance effect), that were nearly twice as large as those taking place while waiting motionless for nearly 10 s prior to movement initiation. This observation suggests very strongly that time per se is not the essence of the distance effect, but that it is movement duration that causes it. In addition, the results of the supplementary analysis reported in Experiment 2 indicate that the distance effect does not appear to be linked to movement length per se but rather to movement duration, a position supported by the reversal of the distance effect observed for the experimental group in Experiment 1. Taken together the above observations suggest that aiming to remembered target location interferes with its retention in memory, and that it is this interference that causes the distance effect.

### Coding location of remembered target

When a target is extinguished prior to movement initiation, its location remains available in iconic memory for a short period of time (Lemay & Proteau, 2001 ; Elliott & Calvert, 1992; Elliott & Madalena, 1987). Moreover, the results of partial report studies suggest that all the information available in the visual scene can be recalled (Sperling, 1960). In that vein, Elliott and Calvert (1992) had participants perform a manual aiming task in a condition in which a single target could be used or while two targets could be presented at the same time. Participants performed the task in a normal vision condition, or in conditions in which all visual information was eliminated at the initiation of the aiming movement, at the presentation of a reaction signal, or two seconds prior to the reaction signal. The authors showed that the aiming error increased significantly from one of the above defined conditions to the other, and was larger in the choice task than when a single target was used. However, the difference in aiming error found between the single and the choice conditions did not increase significantly as a function of the period of occlusion, which led the authors to propose that participants retained information 'about the layout of the movement environment' rather than about a single target location. Additional evidence that iconic memory intervenes when pointing to recently extinguished targets is available in the present study.

In the first experiment of the present study, participants had a higher peak velocity for a 100 ms than for a 10000 ms recall delay, whereas in the second experiment, peak velocity was higher when pointing to remembered targets than when pointing to visible targets. Similar observations have been reported by Lemay and Proteau (2001). They reported that the increase in peak velocity noted for shorter than for longer recall delays was totally eliminated in a masking condition –which is thought to 'erase' the content of iconic memory (i.e., Elliott, Calvert, Jaeger, & Jones, 1990 ; Lowe, 1975; Sperling, 1960) - while that variable error of aiming was larger in a mask than in a no mask condition. Taken collectively, the results reported by Elliott and Calvert (1992), Lemay and Proteau (2001) and in both experiments of the present study, suggest that having a target representation in iconic memory favors aiming performance.

However, even when target location is available in a visual form such as in iconic memory, the results of the present study suggest that it is still required that the target location be recoded in an egocentric frame of reference for movement planning and control purposes (viewer-centered and/or arm centered frame of reference; Carrozzo et al., 1999; McIntyre et al., 1998; Soechting & Flanders, 1989a, b; Vindras & Viviani, 1998). This is the case, because in Experiment 1 the distance effect did not differ significantly between the short recall delay, when target location was presumably available in iconic memory, and the long recall delay when it clearly was not. Taken together, the above observations suggest that the iconic representation of the target can be used to update its egocentric representation.

In addition, finding a very similar distance effect after both a short and a long recall delay in Experiment 1 suggests that target location was recoded in the same frame of reference, body and/or arm-centered (Carrozzo et al., 1999; Chieffi et al., 1999; McIntyre et al., 1998; Vindras & Viviani, 1998), in both recall conditions. This egocentric target representation, the resulting movement representation, or one's evaluation of his or her initial hand position (Vindras, Desmurget, Prablanc, & Viviani, 1998; Wann & Ibrahim, 1992) would decay over time, which would explain at least partially the larger variable error and absolute constant error found in Experiment 1 for the longer than for the shorter recall delay (see also Lemay & Proteau, 2001 for a similar finding). The distance effect would result from interference between movement execution and maintaining this egocentric representation of the target location. Future work should address this possibility.

Finally, the results of the present study indicated that aging does not affect pointing to remembered targets. At least, this is the case when the task does not require that participants initiate and execute their movement as fast as possible. This conclusion is supported by recent evidence showing that the retaining of egocentric spatial information does not decrease with age (Desrocher & Smith, 1998).

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Table 1.
Mean (and standard deviation) of movement time, absolute constant error, variable error, and movement peak velocity as a function of group, recall delay and target location for a target presentation time of 50 ms. Experiment 1.

| Delays | | 100 ms | | 10000 ms | |
|---|---|---|---|---|---|
| Targets location | | Near | Far | Near | Far |
| Groups | | | | | |
| | | Movement time (ms) | | | |
| Younger | Control | 1031 (462) | 1343 (529) | 1059 (398) | 1464 (589) |
| adult | Experimental | 3085 (559) | 823 (123) | 2999 (682) | 899 (203) |
| Older | | 954 (307) | 1234 (375) | 1135 (515) | 1428 (571) |
| adult | Control | 3066 (679) | 950 (211) | 3365 (615) | 953 (130) |
| | Experimental | | | | |
| | | Absolute constant error (mm) | | | |
| Younger | Control | 17.2 (16.6) | 25.6 (15.4) | 34.4 (26.6) | 41.5 (23.2) |
| adult | Experimental | 43.6 (15.8) | 36.7 (27.4) | 40.9 (26) | 24.6 (11.2) |
| Older | | 33.7 (24) | 62.1 (42.1) | 40.3 (31.3) | 50.5 (46.9) |
| adult | Control | 43.5 (19.2) | 35.4 (26.7) | 54.7 (32.9) | 52.5 (30.4) |
| | Experimental | | | | |
| | | Variable error (mm) | | | |
| Younger | Control | 19.9 (6.3) | 29.5 (15.2) | 22.9 (8.7) | 33.3 (15.1) |
| adult | Experimental | 31.9 (13.2) | 19.1 (10.2) | 33.2 (20.2) | 21.5 (6.2) |
| Older | | 23.3 (8.4) | 27.5 (14.8) | 26.4 (11) | 38.5 (25.8) |
| adult | Control | 27.6 (8.6) | 21.7 (9.8) | 37.8 (21.9) | 24.8 (10) |
| | Experimental | | | | |
| | | Movement peak velocity (mm/s) | | | |
| Younger | Control | 278 (121) | 442 (177) | 195 (84) | 373 (138) |
| adult | Experimental | 73 (14) | 827 (248) | 84 (40) | 773 (247) |
| Older | | 302 (98) | 511 (154) | 243 (72) | 417 (144) |
| adult | Control | 81 (27) | 675 (194) | 79 (33) | 652 (197) |
| | Experimental | | | | |

Table 1 (continued)

Mean (and standard deviation) of movement time, absolute constant error, variable error, and movement peak velocity as a function of group, recall delay and target location for a target presentation time of 500 ms. Experiment 1.

| Delays | | 100 ms | | 10000 ms | |
|---|---|---|---|---|---|
| Targets location | | Near | Far | Near | Far |
| Groups | | | | | |
| | | Movement time (ms) | | | |
| Younger adult | Control | 1067 (338) | 1334 (430) | 1208 (405) | 1495 (568) |
| | Experimental | 3141 (444) | 824 (102) | 2948 (469) | 831 (98) |
| Older adult | Control | 1009 (211) | 1208 (266) | 1144 (307) | 1398 (379) |
| | Experimental | 3053 (839) | 950 (177) | 3227 (953) | 919 (123) |
| | | Absolute constant error (mm) | | | |
| Younger adult | Control | 16.8 (18.7) | 20.8 (16.3) | 22.7 (20.3) | 43 (36.1) |
| | Experimental | 34.4 (14.2) | 23.7 (10.7) | 49.2 (21.1) | 26.1 (14) |
| Older adult | Control | 34 (23.5) | 53 (33.3) | 29.2 (22.4) | 48.5 (34.6) |
| | Experimental | 41.7 (22.8) | 39.3 (41) | 52.4 (33.3) | 48.1 (38) |
| | | Variable error (mm) | | | |
| Younger adult | Control | 19.1 (7.1) | 21 (10.1) | 21.3 (7) | 27.4 (10.8) |
| | Experimental | 29.2 (12) | 14.9 (5.5) | 37.7 (12.1) | 19.6 (8.5) |
| Older adult | Control | 18.7 (10.5) | 26.3 (21.3) | 24.5 (8.8) | 20.8 (4.8) |
| | Experimental | 26 (10.1) | 20.3 (8.6) | 35.1 (31.7) | 21.3 (7.2) |
| | | Movement peak velocity (mm/s) | | | |
| Younger adult | Control | 238 (101) | 418 (145) | 194 (85) | 324 (139) |
| | Experimental | 80 (18) | 809 (253) | 76 (21) | 791 (253) |
| Older adult | Control | 271 (68) | 495 (129) | 238 (80) | 422 (104) |
| | Experimental | 84 (29) | 633 (161) | 87 (26) | 637 (215) |

Table 2.

Mean (and standard deviation) of variable error, absolute constant error, movement time and movement peak velocity as a function of target visibility and of target location. Experiment 2.

| Target | Near | Far |
|---|---|---|
| | Variable error (mm) | |
| Visible | 19,4 (2,9) | 18,9 (4,7) |
| Remembered | 18,4 (2,9) | 24,2 (6,5) |
| | Absolute constant error (mm) | |
| Visible | 20,3 (13,4) | 15,6 (12,1) |
| Remembered | 19,2 (18,4) | 19,6 (15,2) |
| | Movement time (ms) | |
| Visible | 1567 (387) | 1986 (469) |
| Remembered | 1372 (421) | 1725 (526) |
| | Movement peak velocity (mm/s) | |
| Visible | 177 (55) | 307 (93) |
| Remembered | 235 (93) | 359 (134) |

# Authors' note

This study was supported by a grant from the National Science and Engineering Research Council of Canada (L.P.). All correspondence concerning this article should be addressed to Luc Proteau, Département de kinésiologie, Université de Montréal, Station postale 6128, Succursale Centre ville, Montréal, Canada, H3C 3J7.

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# Figure captions

Figure 1. Sketch of the apparatus. Pointer is seen on the starting position. All possible target locations are illustrated.

Figure 2. Mean results of Experiment 1. Participants of the experimental group completed their movement within the allowed movement time and movement time was longer for the farther than for the nearer targets for the control group, (upper left panel). Results of the absolute constant error (lower left panel) and of the variable error (upper right panel) of aiming show a significant distance effect for the control group and a significant but reversed distance effect for the experimental group. Peak movement velocity (lower right panel) was higher for the farther than for the nearer targets and more so for the experimental than for the control group.

Figure 3. Mean results of Experiment 2. Results of the variable error of aiming (lower panel) show a significant distance effect when pointing to remembered targets but not when pointing to visible targets. The absolute constant error of aiming (upper panel) was not modified by either target location or target visibility.

Figure 4. Variations in movement time (left axis, open markers) and in the variable error of aiming (right axis, filled markers) when pointing to remembered targets (left panel) and to visible targets (right panel). The lower ordinate refers to block number when trials were ranked from the slowest to the fastest (block 18). The upper ordinate indicates mean target location for each block of trials. Note that, when pointing to remembered targets located approximately at the same distance from the starting base, the variable error of aiming increases as a function of movement duration. No such trend is apparent when pointing to visible targets.

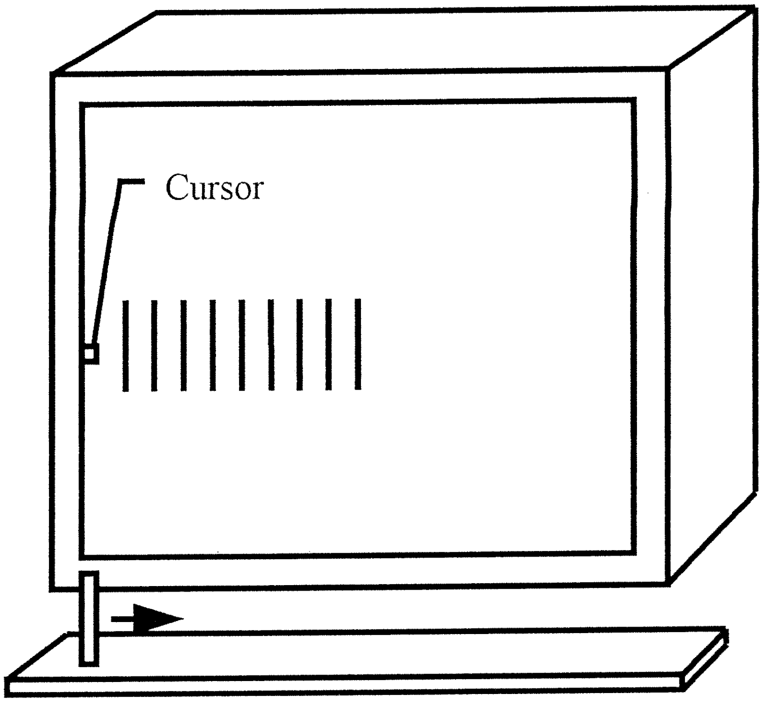
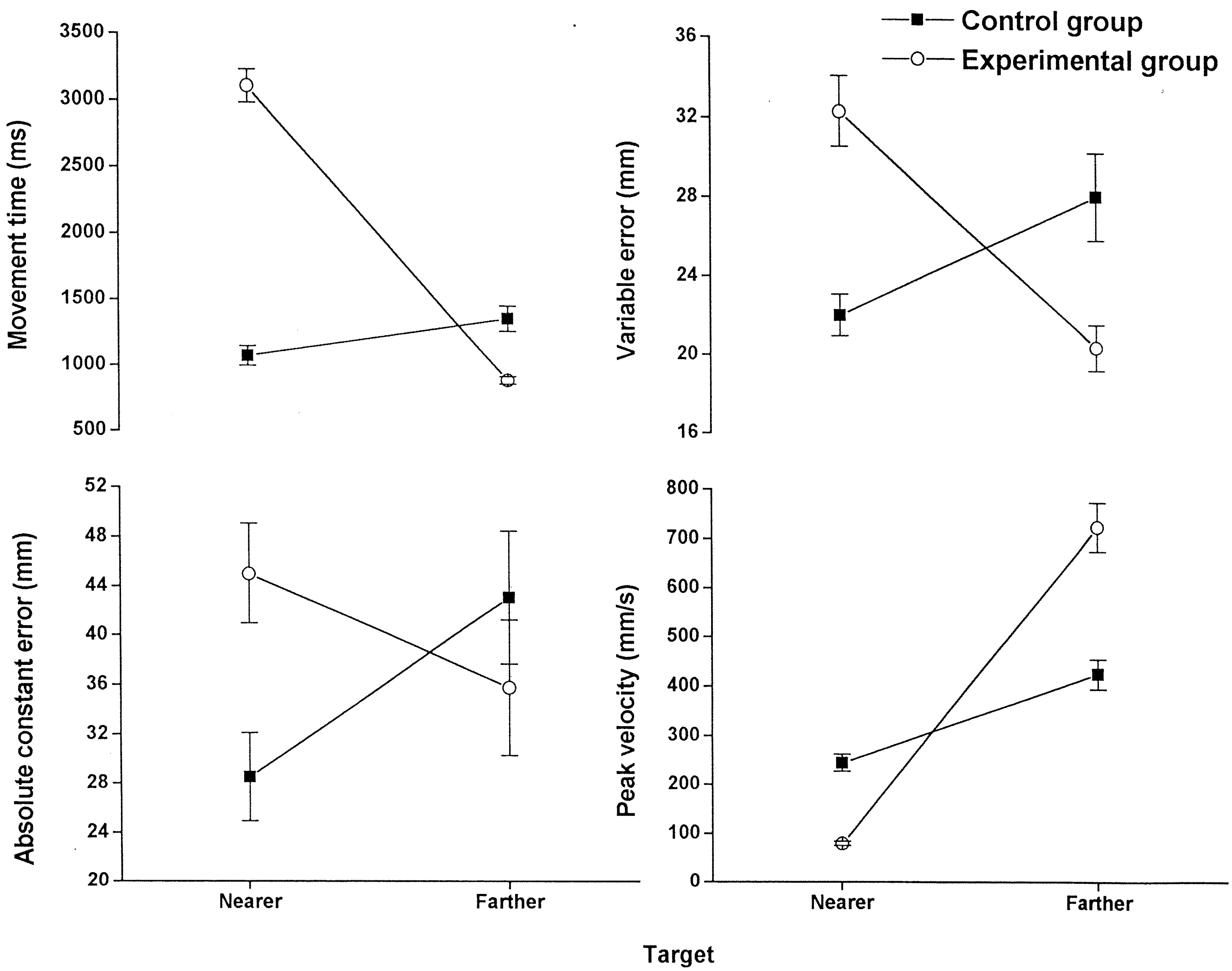
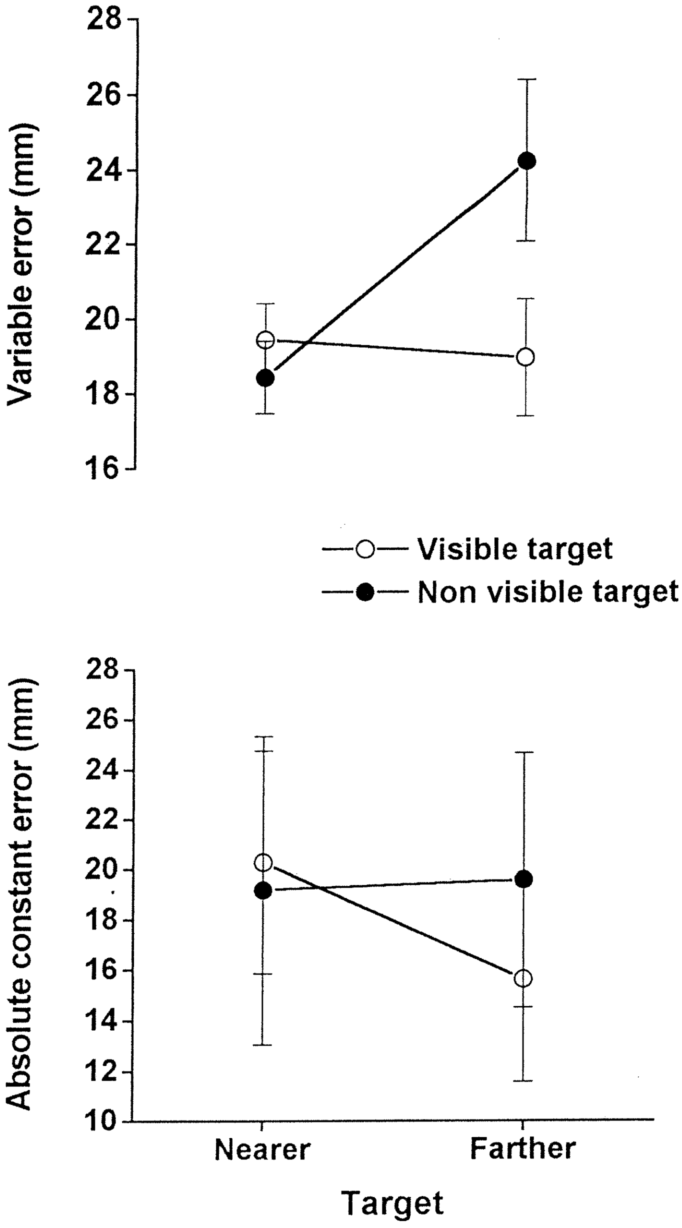
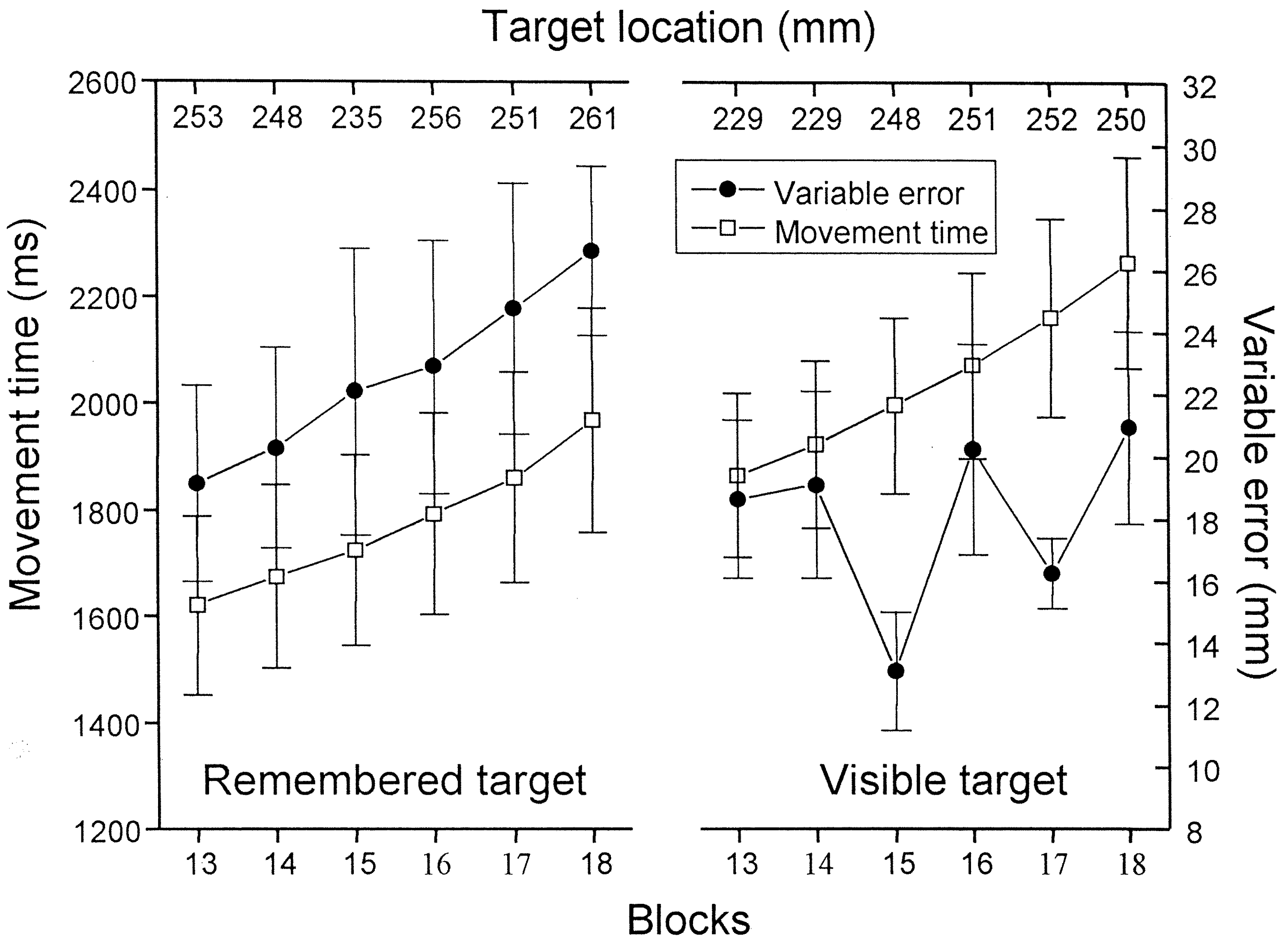


Figure 1


Control group
Experimental group
Movement time (ms)
3500
3000
2500
2000
1500
1000
500
Variable error (mm)
36
32
28
24
20
16
Absolute constant error (mm)
52
48
44
40
36
32
28
24
20
Peak velocity (mm/s)
800
700
600
500
400
300
200
100
0
Nearer
Farther
Nearer
Farther
Target


Variable error (mm)
28
26
24
22
20
18
16
—○— Visible target
—●— Non visible target
Absolute constant error (mm)
28
26
24
22
20
18
16
14
12
10
Nearer
Farther
Target


Target location (mm)
253
248
235
256
251
261
229
229
248
251
252
250
Movement time (ms)
2600
2400
2200
2000
1800
1600
1400
1200
Variable error (mm)
32
30
28
26
24
22
20
18
16
14
12
10
8
Variable error
Movement time
Remembered target
Visible target
13
14
15
16
17
18
13
14
15
16
17
18
Blocks

# CHAPITRE 4

## ARTICLE 3

# Manual Pointing to Remembered Target …But Also in a Remembered Visual Context

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Running title: Manual aiming to remembered targets

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# Abstract

In this paper we investigated whether visual background information available during target presentation influences manual pointing to remembered targets. Younger and older participants manually pointed with their unseen hand to remembered or visible targets that were presented over a structured visible background or not. The results indicated that a structured visual background biased movement planning processes, but did not influence motor control processes, regardless of the fact that target location and the background were visible or remembered. Thus, visual background provides information used for encoding target location that can be maintained in a short term sensory storage. How one uses visual background information for movement planning is not mediated by aging.

Key words: Visual background, iconic memory, short-term sensory storage, manual aiming, aging, movement kinematics, motor planning, motor control, remembered targets

## Introduction

Aiming movements towards visual targets are amongst the most frequently performed movements of our repertoire. These movements are most accurate when one's hand is visible throughout the movement towards a visible target, [1, 2] become less accurate when one's hand is not visible during movement execution,[3, 4] and are least accurate when the target is no longer visible as movement unfolds.[5-7] However, if movement initiation quickly follows target extinction (<2 s), it has been shown that movement accuracy was less affected by target extinction than when longer recall delays were used, presumably because target location remained available in iconic memory. [5, 6, 8-10]

The methodology used in all the studies interested in aiming movements towards remembered targets was of one of three types. First, the target is presented and then: (a) the lights of the experimental room were turned off, (b) spectacles wore by the participants turned from transparent to translucent, or (c) the participants are asked to close their eyes, prior to movement initiation. Regardless of the methodology used, the authors concluded that the increase in error noted when pointing to remembered targets in comparison to visible targets was caused by the withdrawal of visual information about target location. However, in all cases vision of the surrounding context, hereafter called visual background information, had been withdrawn concomitantly with that of the target. In that regard, recent evidence suggests that surrounding the target with a structured visual background facilitates evaluation of the distance (but not direction) between the starting position of one's hand and the target location when the elements composing that background are located between the starting base and the target location. [11, 12]

To our knowledge, Barry, Bloomberg, and Huebner (1997) published the only report on the role of a visual context on aiming accuracy towards remembered targets. The target was either presented at the center of a screen or at more peripheral locations (up to 11° of visual angle). In addition, this target could appear on a uniform and featureless background or over a visual scene projected on the screen. The key element of that visual scene was a road running from the top to bottom of the screen at its lateral center. First, participants foveated the target, and then the screen and the lights in the experimental room were turned off. Following a 2-4 s delay, participants pointed a laser beam to the remembered location of the target. The results indicated that participants were always biased to the right of the target, with the exception of when it was presented at the center of the screen in the foreground of the visual scene for which there was no bias. Barry et al. (1997) interpreted these results as indicating that the key element of the visual background provided a clear indication of the straight ahead position, which might have helped participants to align their internal representation of their body midline with a visual memory of the straight ahead position that apparently persisted for at least four seconds. Presumably, this information could not be used when the target was presented at off-center locations, at least when relatively long recall delays are used. However, because pointing variability was not reported in that study, and considering that it is considered as the best indicator of target retention, [14-17] a firm conclusion cannot be reached on this issue.

This brief review of the literature indicates that visual background information, actual or remembered, might be useful for the planning and control of aiming movements. However, when relatively long recall delays are used, background visual information apparently only benefits aiming to a restricted area of the environment. Considering that iconic information concerning target location can be used to enhance accuracy of aiming movements directed at remembered targets regardless of their location, the question that arises is whether visual background information would influence movement planning and/or control, regardless of target location in the visual field, when recall delays compatible with iconic storage of information are used. The main goal of the present study was to gain information in that regard. To reach our goal participants were ask to aim at the remembered location of a target that had been presented on a computer screen for only 500 ms. In one condition, the target appeared on a black featureless background. In a second condition, the target was visible over a structured visual background. If the presence of a visual background influences target encoding and retrieval, pointing performance should differ as a function of its presence or absence. Finally, we wanted to determine whether the role played by visual background information on movement planning and control would be mediated by aging. This could be the case because older adults have been shown to have a more restrained attentional scope than younger adults[18] which might result in them focusing more on the target per se and paying less attention to the visual background than younger participants.

## Materials and Methods

### Participants

Ten younger adults (M: 24.4 years old, SD : 3.27 years) and ten older adults (M: 70.4 years old, SD: 4.12 years) took part in this study. All participants were self-declared right handed, had good upper limb mobility and did not have any visual deficit except those corrected by prescription lenses. The younger participants were all students in the Département de kinésiologie at the Université de Montréal. All older participants lived in their own residences and reported being in good health. All participants were paid for their time and were unaware of the purpose of the study. This study has been approved by the local ethics committee.

### Tasks and apparatus

Participants moved a pointer at one of nine possible targets presented on a computer screen. The task was very much like dragging one's finger on the screen from a fixed starting position to a target shown on the screen, however without touching it. A cardboard shield prevented the participants from viewing their upper limb or the pointer. All targets were white (on a black background), with a width of 3.2 mm and a height of 64.5 mm. The first target was located at 129 mm from a fixed starting base aligned with the left edge of the computer screen. The distance between each target was of 22.5 mm. The pointer was connected to an optical encoder (sampling rate of 500 HZ, spatial precision of 0.17 mm), sampled by a microcomputer. In the no background condition, the only visual information provided on the screen was that of the starting base and of the target. In the visual background condition, there were four white vertical lines drawn from the top to the bottom of the screen. They were located at 118.6 mm, 185.6 mm, 252.7 mm, and 319.7 mm from the starting base, respectively. When available the visual background information was introduced at the same time as the target.

Procedure

Participants gazed at the screen before the beginning of each trial. Once the pointer was positioned at the starting position, the target and, when available, the visual background were presented on the computer screen. In the remembered information condition, they remained visible for 500 ms. In this condition, participants wore liquid crystal goggles, which changed from transparent to translucent immediately after target presentation, thus instantaneously (~ 3 ms) depriving participants of all visual information. One hundred milliseconds later, an auditory stimulus indicated that movement could start. In the visible information condition, the target and all other visual information available remained visible throughout movement execution. To recreate the timing condition found in the remembered target condition, a tone invited participants to start their movement 600 ms after target presentation.

For each of the remembered information and of the visible information conditions, each participant completed 100 trials in the no background condition and 100 trials in the background condition. The order of presentation of the latter conditions was counterbalanced across participants. However, the visible target condition was always performed last to prevent participants from transferring information available in this condition to the remembered target condition. Each condition began with a set of 10 acclimatizing trials, which were not considered in the different analyses. Then, the participants performed 90 experimental trials. Each of the nine possible targets was used once in each one of 10 consecutive blocks of trials. No knowledge of results was provided.

Dependent variables. The main dependent variables of the present study were the constant error and the variable error of aiming. The first one is the mean signed aiming error, which is used to determine whether aiming movements show a bias (undershooting or overshooting of the target). We chose this dependent variable because Coello and Magne (2000) showed that aiming in the absence of a visual background caused a large undershooting of the target location. The variable error of aiming is the within-participant standard deviation of the individual movement endpoints. It is considered to reflect forgetting of the location of the target. [14-17]

In addition, to determine whether the availability of a structured visual background affects movement planning and/or movement control, we evaluated the constant error of aiming at the end of the first movement impulse [19] which is thought to reflect response planning processes. To this end, the displacement data of the cursor over time were first smoothed using a fourth order recursive Butterworth filter with a cutting frequency of 10 Hz. The smoothed data were then numerically differentiated once using a central finite technique to obtain the velocity profile of the aiming movement, a second time to obtain its acceleration profile, and a third time to obtain its jerk profile. From these profiles, we measured the time required by the participants to complete the task (movement time), the distance covered by the movement first impulsion, the proportion of movement time spent after peak deceleration of the first movement impulse, and the proportion of trials showing at least one correction to the initial movement impulse. Movement time is defined as the delay taking place between movement initiation and movement completion. In the framework of the present study the end of the movement first impulse was detected when one of the three following situations occurred: (a) the velocity profile went from positive to negative, indicating a movement reversal; (b) the acceleration profile crossed the zero line for a second time, indicating a second impulse, or (c) when the acceleration profile showed a significant discontinuity during the deceleration phase of the movement (i.e, the jerk profile went from negative to positive at the moment of occurrence of the discontinuity noted on the acceleration profile). By the same token, movements showing any one of the above kinematic characteristics were considered as showing one correction. Finally, the proportion of movement time spent after peak deceleration is considered to reflect the duration of on-line control processes.

## Results

To reach our goals the data of the dependent variables defined above were individually submitted to a 2 age groups (younger vs. older) x 2 vision conditions (remembered information vs. visible information) x 2 background conditions (absent vs. present) x 9 targets ANOVA using repeated measurements on the last three factors. Significant main effects and interactions ($p < .05$) were broken down by using the Newman-Keuls technique ($p < .05$).

Aging and Vision condition did not affect significantly any dependent variable as a function of the presence or the absence of background visual information. However, as illustrated in Figure 1, aiming in the presence of a structured visual background resulted in a significant undershooting of the proximal targets (targets 1 and 2) and in a significant overshooting of the distal targets (targets 8 and 9) in comparison to the no background condition, F (8, 144) = 13.21. These biases were readily observable at the end of the first movement impulse, F (8, 144) = 9.79 indicating that the presence of a background influenced movement planning processes. As could be expected, the spatial biases noted in the visual background condition resulted in shorter movement time for the proximal target and in longer movement time for the distal target in comparison to the no background condition (however, only for targets 1 and 9, respectively), F (8, 144) = 5.36. Movement variability (see Figure 1) was not influenced by the presence or absence of a structured visual background (p > .20), nor were the proportion of corrected trials (62 % vs. 64%, respectively) and the proportion of movement time spent after peak deceleration (62% vs. 64 %, respectively), (p > .20 in both cases).

Finally, for both age groups movement endpoint variability was not affected by target location when pointing in the visible information condition (fluctuates between a minimum of 16.6 mm for target 8 and a maximum of 18.5 mm for target 6), whereas variable error increased significantly between targets 1-3 (19.3 mm) and targets 7-9 (24.2 mm) when pointing to remembered targets, F (8, 144) = 3.69.

## Discussion

The presence of a visual background modified aiming performance, but not maintaining of target information in iconic memory. If the presence of a background had facilitated (or interfered with) retention of the target location in memory we should have noticed a smaller (or a larger) movement endpoint variability when a background was present than when it was not. [14-17] This was not the case. However, endpoint variability increased as a function of target distance only when pointing on the basis of remembered information. This ‘distance effect’ has been reported in the past, [20-21] and we have recently shown that it is caused by movement execution interfering with the stored target representation, [5] a proposition that is substantiated by the observation that a distance effect did not take place in the present study when pointing to visible targets. The results of the present study indicate that this interference is not modified by the presence of a structured background during target presentation.

The results indicated that background information, regardless of the fact that it is visible or remembered, modified movement planning, as indexed by the constant error at the end of the movement first impulse, and not on-line correction processes, as indexed by the proportion of corrected trials and the proportion of time spent after peak deceleration. In line with Coello and Magne (2000), it appears that the number of background elements present between the starting position and the target (i.,e., vertical lines in the present case) modified the perception of the distance between these two points. We replicated this finding when pointing in a visual context and extended this by showing a similar effect when pointing on the basis of remembered target and background information. This supports previous observations that all information available in the visual array is available in iconic memory, [8, 10] and adds to this information in that background visual information or its iconic representation are used similarly for movement planning purposes.

In addition, in line with previous work from our laboratory, [5-6] the results of the present study clearly indicate that aging neither mediates coding, maintaining and retrieving of visuo-spatial information stored in iconic memory, nor the processing of background visual information for movement planning. The latter aspect of the results appears to be at odds with the results reported by Kosslyn et al. (1999) who showed that older participants have a more restrained attentional scope than younger adults . However, in that study participants had to detect whether one or two target stimuli were presented in a small or large visual array whereas in the present study participants had to pay attention to a single target that was part of a larger visual scene. This suggests that in the present study the target was processed as an element of the information contained in the visual array rather than each element of the visual array being processed as individual entities.

## Conclusion

The results of the present study showed that a visual background modified aiming accuracy regardless it being visible or available in iconic memory. Barry et al. (1997) reported that background information helped participants to be more accurate when the target was located in the center of the screen than at more peripheral locations, because in their study it helped participants better define a straight ahead position. Coello and Magne (2000) noted a decrease in constant error with an increase in the number of background elements between the starting base and the target. In the present study, the presence of a background did not improve aiming accuracy for the central targets in comparison to the no background condition. Rather, the presence of a background biased movement endpoint for the proximal and the distal targets. These observations suggest that information in the visual background modifies the perception of the distance between the starting base and the target, not that it results necessarily in a more accurate estimation of it. This underlines the need for more work on this issue to help define visual background information that would help participants in locating visual targets and remembering their locations.

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# Acknowledgment

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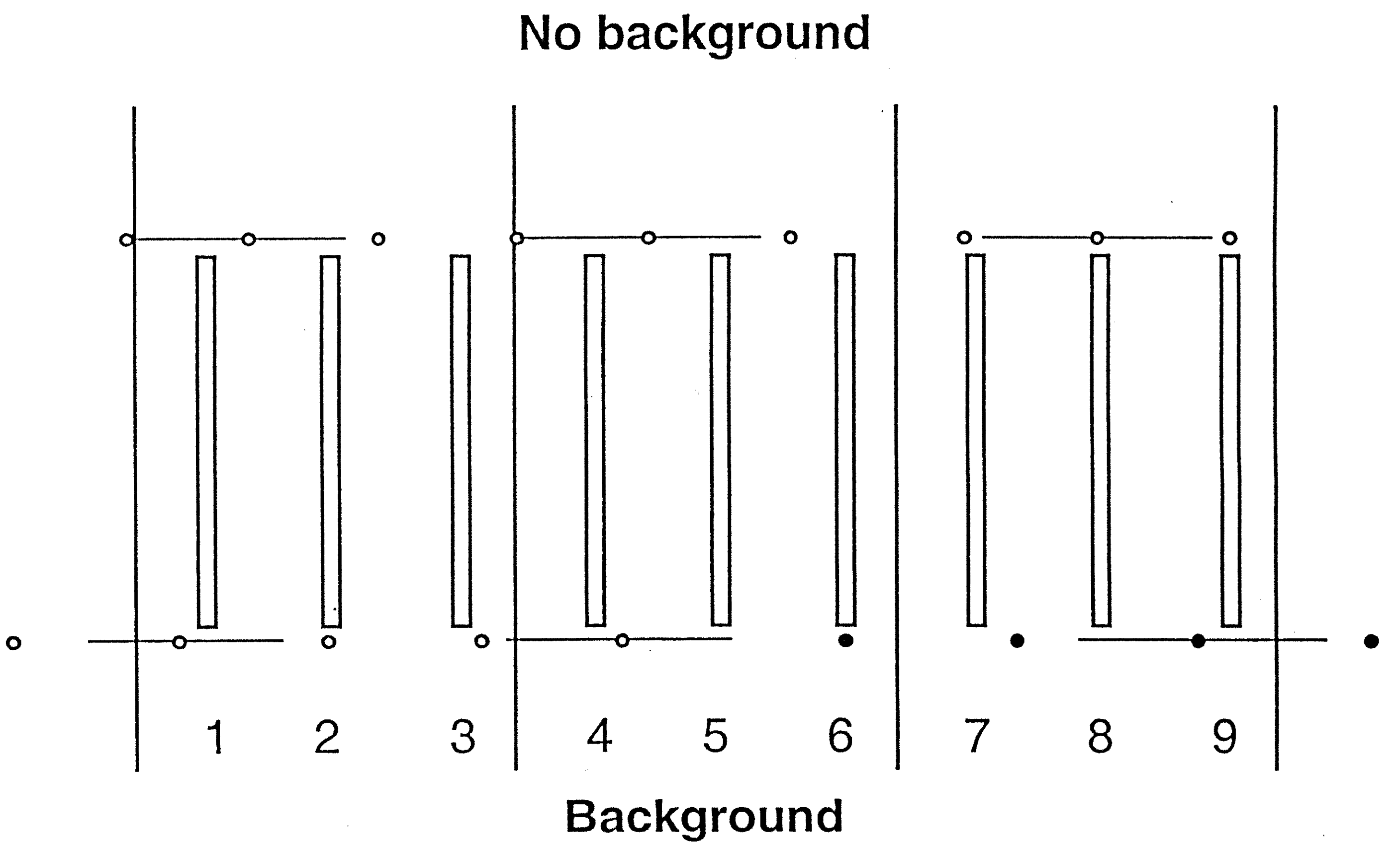
# Figure captions

Figure 1. Constant error and variable error of pointing as a function of target locations (identified as 1 to 9) and of background condition. The longer vertical line at the left of the figure indicates the starting position; the shorter vertical lines were used as background visual information. The small dots illustrate mean endpoint position. Open markers are used to illustrate a target undershooting whereas the filled markers are indicative of a target overshooting. The first marker illustrates mean endpoint location for target 1, the second marker illustrates mean endpoint location for target 2, and so on. Note the large undershooting of targets 1-3 and overshooting of targets 7-9 in the background condition. The horizontal lines indicate the mean variable error (within-participant standard deviation; endpoint plus and minus one standard deviation is illustrated) of aiming. For clarity, variable error is only illustrated for targets 2, 5 and 7. Note the increase in variable error as a function of target location. Drawn to scale.


No background
1
2
3
4
5
6
7
8
9
Background

# CHAPITRE 5

## ARTICLE 4

# Aging affects pointing to unseen targets encoded in an allocentric frame of reference

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Running title: Manual aiming to remembered targets

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## Abstract

The goal of the present study was to determine whether aging influences aiming performance to a remembered target encoded in an allocentric frame of reference. We presented four targets simultaneously. The targets were then withdrawn from the screen. Following a recall delay, only three of the targets were presented on the screen in the same configuration as before but at a different location from their first presentation. We asked participants to point first to the missing target. Because participants did not know where on the computer screen the targets would be presented at the end of the recall delay, they had no choice but to use an allocentric frame of reference to encode its location when the targets were first presented. The results indicate that older participants were significantly more variable when pointing to the remembered target than their younger counterparts, suggesting a decline of allocentric spatial memory with aging.

Key words : Aiming, aging, allocentric memory, movement planning, movement control

# Aging affects pointing to unseen targets encoded in an allocentric frame of reference

The execution of manual aiming movements puts into play a series of processes that combines visual information from the coveted target, the visual context in which this target is embedded and the location of one's hand, as well as proprioceptive information concerning the location of one's hand both prior to movement initiation and during movement execution. In the process of translating sensory information about target location and initial arm position into appropriate motor commands, endpoint position of reaching has been shown to be first specified in a viewer-centered frame of reference (Carrozzo, McIntyre, Zago, & Lacquaniti, 1999; McIntyre, Stratta, & Lacquaniti, 1997, 1998), and then transformed in a body-centered frame of reference (Carrozzo et al., 1999; McIntyre et al., 1997,1998; Soechting & Flanders, 1989a, b) and perhaps being transformed even further in a hand-centered frame of reference (Gordon, Ghilardhi, & Ghez, 1994; Vindras & Viviani, 1998; Vindras, Desmurget, Prablanc, & Viviani, 1998; see also McIntyre et al., 1998). These transformations are thought to induce systematic pointing biases (McIntyre et al., 1998). Besides errors resulting from this series of transformations, it has been shown that part of the increase in error occurring when one points with his or her unseen hand towards a visual target is also caused by an incorrect estimation of the initial position of one's hand prior to movement initiation, resulting in movement planning errors (Vindras et al., 1998; Vindras & Viviani, 1998 ; however see Bédard & Proteau, in press).

When one points to a target that disappears prior to or during movement execution (Adamovich, Berkinblit, Smetanin, Fookson, & Poizner, 1994; Soechting & Flanders, 1989a), its kept location in memory degrades over time resulting in an increase in pointing variability (McIntyre et al., 1997). Further, this degradation over time is similar regardless of aging suggesting that egocentric information about the target location is not affected by aging.

The above conclusions were reached for situations in which the participants were presented with a single target to remember. In these situations, it might be advantageous to code the target location as a function of oneself because it provides one with a relatively stable frame of reference. However, this egocentric coding might not be efficient and/or sufficient when one must remember the location of multiple targets. In this situation, it might be advantageous to code the location of the targets one relative to the others, or put into other words into an allocentric frame of reference. Our objective in the present study was to determine whether aging would affect aiming performance of a movement directed to a target location coded in an allocentric frame of reference.

The importance of allocentric information for movement planning and control has been first suggested by Conti and Beaubaton (1980), and recently demonstrated very convincingly by Coello and Magne (2000). The latter authors had participants aimed at visible targets with their unseen hand. They showed that, if a series of visual landmarks were located between the starting position and the target, participants were more accurate on the extent dimension of the task (but not on its direction component) than when such markers were not available. As it is the case for movements performed towards a visible target, the visual context in which the target is presented also influences aiming performance to remembered target locations (Barry, Bloomberg, & Huebner, 1997; Lemay, Gagnon, & Proteau, 2001). For example, Lemay et al. (2001) had participants aimed at a remembered target after a short recall delay (100 ms) that had been presented alone on a uniform background or over a background divided in different areas by vertical lines. The presence of a background for both older and younger adults resulted in a significant undershooting of targets located near the starting base and in a significant overshooting of targets located far from the starting base, whereas no such biases were found when targets were presented on a uniform background. The noted biases were observable at the end of the movement first impulse (Meyer, Abrams, Kornblum, & Wright, 1988), indicating that the visual background information biased movement planning processes.

The observation that visual background information biased aiming performance similarly for older and younger suggest that it biased the frame of reference in which the target was presented similarly for older and younger adults. However, there is evidence that the maintaining of information for a relatively long time in an allocentric frame of reference becomes deficient with aging (Desrocher & Smith, 1998; Zelinski & Light,1988). For example, Desrocher and Smith (1998) presented participants with 60 pairs of objects at a rate of approximately one pair every eight seconds. Each pair was presented for four seconds during which participants had to name the two objects and to point at each one of them. Then there was a filled interval of four seconds (participants counted backwards form a number chosen randomly) before the next pair of objects was introduced. After the sixty pairs had been presented, participants filled neuropsychological tests for 30 minutes. At the end of this delay, half of the participants were given each object alone and were asked to recall the exact location at which it had been presented, which presumably measured their capability of remembering egocentrically coded information. The other half of the participants were given a pair of object and were asked to recall the location of both the objects which presumably measured their capability at remembering allocentrically coded information (one object in relation to the other). The results indicate that younger and older participants performed the egocentric task similarly but that the younger participants outperformed their elders in the allocentric task, suggesting that there is a decline in maintaining allocentrically coded information with aging. If this is really the case, we should be able to show that pointing variability to an allocentrically coded target location increases with aging.

To reach our goal, precautions were taken to ensure that participants encoded the target in an allocentric frame of reference. Participants were presented with four targets simultaneously on a computer screen so that they could encode their location one relative to another. Then, following a 10 seconds recall delay, three of the four targets were shown to the participants in the same configuration as before but at a different location on the computer screen. The participants task was to point manually to each of the four targets presented initially, but at their new location and beginning with the missing target. Because participants did not know where on the computer screen the targets would be presented at the end of the recall delay, they had no choice but to use an allocentric frame of reference to encode the location of the target when they were first presented. In addition, participants were allowed to see their movement as it progressed from the starting base towards each of the targets that had to be reached. This make it superfluous to encode target location in an egocentric frame of reference (Berkinblit et al., 1995), while eliminating the possibility that difference in aiming performance could be attributed to deficiencies in processing proprioceptive information about one's movement with aging (Chaput & Proteau, 1996; Warabi, Noda, & Kato, 1986). If aging results in a deterioration of allocentrically coded information, older participants pointing performance should be more variable and perhaps even less precise than that of their younger counterparts.

## Method

### Participants

Ten younger (M = 21.9 years, SD = 1.7 years) and eleven older (M = 73.8 years, SD = 4.7 years) participants took part in this experiment. All participants were self-declared right handed, had good upper limb mobility and did not have any visual deficit except those corrected by prescription lenses. The younger participants were all students in the Département de kinésiologie at the Université de Montréal. All older participants lived in their own residences and reported being in good health. All participants were paid for their time and were unaware of the purpose of the study. This study has been approved by the local Ethics Committee.

### Task and Apparatus

The task was to move a pointer from a fixed starting position in turn towards each one of four targets (one remembered and three visible). The apparatus consisted of a two-degrees of freedom manipulandum, a table, and a computer screen. Participants sat in front of a table supporting the computer screen (Mitsubishi, Color Pro Diamond 37 inches). The computer screen sat on a metallic support, itself resting on top of the table. The distance between the bottom of the computer screen and the tabletop was 12 cm, permitting free displacement of the manipulandum on the tabletop. Participants sat 600 mm away from the computer screen.

The tabletop was covered by a piece of Plexiglas over which a starting base and the manipulandum were affixed. The starting base consisted of an L-shaped piece of aluminium glued to the tabletop and located directly in line with the center of the computer screen and the participants' midline. This made it easy for the participant to position the manipulandum at the beginning of each trial. The manipulandum consisted of two pieces of rigid Plexiglas (43 cm) joined together at one end by an axle. One free end of the manipulandum was fitted with a second axle encased in a stationary base. The other free end of the manipulandum, hereafter called the stylus, was fitted with a small vertical shaft (length: 3 cm, radius: 1 cm) that could be easily gripped by the participant. From the participant's perspective, the far end of the manipulandum was located 40 cm to the left of the starting base and 70 cm in the sagittal plane. Each axle of the manipulandum was fitted with an optical shaft encoder (U.S. Digital, model S2-2048, sampled at 500 Hz, angular accuracy of 0.176°), which enabled us to track the displacement of the stylus on-line and to illustrate it with a 1:1 ratio on the computer screen. The bottom of the stylus and the bottom of the optical encoder located at the junction of the two arms of the manipulandum were covered with a thin piece of Plexiglas. By lubricating the working surface at the beginning of each experimental session, displacement of the stylus was near frictionless.

## Procedures

Once the pointer has been immobilized on the starting base for 500 ms, four white targets were presented on the black background of the computer screen. The targets were presented for 1,000 ms. Each target was 6 mm in diameter and the four targets were presented within an area of 2500 mm$^2$ on the computer screen. The location of each one of the four targets in this 2500 mm$^2$ area was random and varied from one trial to the other. The geometrical centre of this area was located in direct line with the starting base and the participant's midline. Then, following a 10,000 ms recall delay, three of the four targets were presented again on the computer screen in the same configuration as at their initial presentation, but with a different colour and at a different location on the computer screen. For one half of the trials, the geometrical centre of the target area was presented 100 mm above and 100 mm to the right of their initial presentation and for the other half of the trials the geometrical centre of the target area was presented 100 mm above and 100 mm to the left of their initial presentation. The order of presentation of the recall position of the target area was random. The three targets presented at the end of the recall delay were green, yellow, and red. Participants where asked first to point to the location of the missing target in relation to the three remaining targets, stop, and then proceed to point at the green, yellow and red targets, respectively.

Each participant completed 60 trials. The first 10 trials were use for familiarization with the apparatus and procedures. For these trials, participants were informed of the spatial accuracy of their movement (in mm on each one of the movement two dimensions: extent and direction). These trials were not considered in the analyses reported below. For the remaining 50 trials, participants did not receive any feedback.

Dependent variables

The dependent variables of the present study were the variable error and the constant error of aiming, as well as movement time. The variable error of aiming is the within-participant standard deviation of the individual movement endpoints. Variable errors were computed on each dimension of the task. It is considered to reflect forgetting of the location of the target (McIntyre et al., 1997) and is the main dependent variable of the present study. The constant error of aiming is the signed mean aiming error of the participant on each dimension of the task – extent and direction-, which is used to determine whether aiming movements show a bias (undershooting [negative value] or overshooting [positive value] of the target, or aiming to the left [negative value] or the right [positive value]of the target, respectively). This error is thought to reflect transformation errors from one frame of reference to another one. In the present study no such bias was expected because it was thought that the target would be encoded and maintained in an allocentric frame of reference and that movement would occur using the same frame of reference. Movement time is the time delay between movement initiation and movement stop. Movement start was defined as the moment at which the velocity of the cursor moved by the participants exceeded 3 cm/s. Movement was deemed to stop when it did not move by more than 2 mm in any direction for a period of 250 ms. This ensured that participants could make discrete directions to their ongoing movement if they so desired. For each participant, data that differed by more than two standard deviations from the mean of a particular condition were considered as outlier and withdrawn from all analyses.

### Statistical analyses

Each dependent variable was individually submitted to an ANOVA contrasting 2 Age groups (Older vs. Younger) x 4 Targets (remembered target, green, yellow, and red targets) x 2 Recall locations (left or right of initial target presentation area) using repeated measurements on the last two factors. Greenhouse-Geisser correction was applied when the Epsilon value was smaller than 1. Because the correction did not modify the outcome of the analyses, we report the data using the original degrees of freedom. All significant main effects and interactions were further delineated using the Newman-Keuls technique. All effects are reported at $p < .05$.

## Results

### Variable Error of Aiming

The results of the ANOVAs computed on the direction and the extent variable error of aiming both revealed a significant Age group x Target x Recall location interaction, $Fs\ (3, 57) = 3.35$, and 4.34, respectively. As illustrated in Figure 2, participants were more variable on both the direction and extent components of the task for the remembered target than for any of the other three targets which did not differ from each other. Also, older participants were more variable than younger participants, regardless of the target considered. More importantly, the three-way interaction was caused by the fact that the difference in variability observed between the older and the younger participants was significantly larger for the remembered target than for the three remaining targets, a difference that was significantly larger when the target area was located to the right of the screen than to its left.

### Constant Error of Aiming

Concerning the direction component of the task, the ANOVA revealed significant one-way interactions between the Target and the Recall location, F (1, 19) = 5.72, and between the Age groups and the Recall location, F (1, 19) = 6.88. The results of interest are illustrated on the upper panels of Figure 3. The first observation that can be made on Figure 3 is that, overall, participants aimed to the left of the targets presented on the right of the screen, whereas they aimed to the right of the targets presented on the left of the screen. The Target x Recall location interaction reported above indicates that when the target was presented on the right of the screen these biases were significantly larger for the missing target than for the three remaining targets, but not when the target were presented to the left of the screen. The Age group x Recall location interaction indicates that the larger biases noted for the missing target than for the remaining three targets were larger for the older than for the younger participants. The ANOVA computed on the extent constant error did not reveal any significant main effect or interaction ($p > 0.6$). As illustrated on the bottom panels of Figure 3, participants very slightly overshot the location of all four targets.

### Movement time

The ANOVA computed on movement time revealed that it took longer for all participants to reach the remembered target than any one of the remaining three targets, F (3, 57) = 260.1. This is not surprising considering that the remembered target was, on average located at 270 mm from the starting base, whereas the distance between each pair of target was on average of 18.6 mm. The ANOVA also revealed a significant interaction between the Age groups and the Targets, F (3, 57) = 3.65. The breakdown of this interaction indicated that older participants took longer than younger ones to reach the missing target (1943 ms vs. 1623 ms, respectively) but not any one of the three remaining targets (448 ms vs. 473 ms, 419 ms vs. 418 ms, and 473 ms vs. 427 ms, for the green, yellow and red target, respectively).

## Discussion

The goal of the present study was to determine whether aging influences aiming performance to a remembered target encoded in an allocentric frame of reference. Our first step was to ensure that participants would encode target location in an allocentric frame of reference. To this end we presented four targets simultaneously in the middle portion of a computer screen. The targets were then withdrawn from the screen. Following a recall delay, only three of the targets were presented on the screen in the same configuration as before but at a different location from their first presentation. We asked participants to point first to the missing target. Because participants did not know in advance which target would be missing, they had to encode the location of all four targets in relation to one another, or put into other words in an allocentric frame of reference. In addition, because the recall location of the targets was not the same as where they were first presented to the participants, coding individually the location of all four targets in an egocentric frame of reference appears to be an inefficient strategy. Finally, because participants were permitted to see their aiming movements, we encouraged them further to use an allocentric frame of reference for movement planning and control.

The results of the present study are straightforward. They indicate that older participants were significantly more variable when pointing to the remembered target than their younger counterparts. Because older participants took longer than younger ones to reach the first target, it could not be argued that the larger variability was the result of different speed-accuracy trade-offs for the two-age groups (Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979). Similarly, although older participants were more variable than the younger ones for the three visible targets (green, yellow, and red targets), this difference in variability was significantly smaller than that noted for the remembered target indicating that the difference in pointing performance to the remembered target was not caused by perceptual (Fozard, 1990) or motor problems (Darling, Cooke, & Brown, 1989) that could have affected the older participants. Finally, the larger variable error found for the missing target than for the remaining three targets could be partially explained by a distance effect, that is an interference between the stored representation of the target location and movement execution towards this same target (Lemay & Proteau, 2001). Indeed, this is a possibility. However, this distance effect did not differ between older and younger participants in Lemay and Proteau's (2001) study in which a single target was presented and had to be pointed after a 10 s recall delay as in the present study. Thus, the results of the variable error of the present study strongly suggest that aging causes a difficulty in maintaining a stable representation of target location when coded in an allocentric frame of reference.

The above conclusion is consistent with Desrocher and Smith (1998) conclusion that allocentric spatial memory in a configurational task declines with age. The present study adds to the work of Desrocher and Smith (1998) by showing that this decline occurs for a relatively short recall delay (10 seconds in the present study in comparison to 30 minutes in their study) and even when there is relatively little information to maintain in memory (four targets in the present study in comparison to 60 pairs of objects in theirs). It is worth remembering that this decline with age of allocentric spatial memory is not accompanied by a similar decline in egocentric spatial memory. This is the case because in previous work from our laboratory (Lemay & Proteau, in press; Lemay & Proteau, 2001) we have shown that when a unique target is presented and when participants had to point at the exact location of this target after recall delays varying between 0 ms and 10 seconds, the performance older participants did not differ from that of younger ones (see also, Desrocher & Smith, 1998).

The second most interesting aspect of the data reported in the present study is the observation that participants aimed to the left of the remembered target when the recall location was presented on the right of the computer screen, but on the right of the remembered target when the recall location was presented on the left of the computer screen. In addition, these biases were larger for the older than for the younger participants. There are at least two possible explanations of this finding. First, because the four targets were presented initially in the centre of the computer screen, it could be that the participants pointing movement to the remembered target were biased in that direction. That is, an underestimation of the lateral movement of one's hand. At the present time we do not favour this interpretation because no particular biases were noted on the extent component of the task whereas an undershooting of the remembered target would have provided support for this proposition. Second, although we made sure that the location of the four initial targets would be encoded in relation to each other, it could be that the target area (i.e., the portion of the computer screen where the targets were initially presented) was encoded in an egocentric frame of reference. Because this area lied directly in line with both one's midline and the starting position, the initial coding of the target area in a viewer-centered (Carrozzo et al., 1999; McIntyre et al., 1997), hand-centered (Gordon et al., 1994; Vindras & Viviani, 1998; Vindras et al., 1998; see also McIntyre et al., 1998), or midline centered (Bartolomeo & Chokron, 1999) egocentric frame of reference could explain the observed biases. If this is the case, these biases should be eliminated in a situation in which the target area is not modified from its initial position at the time of recall. If such a demonstration could be done, it would indicate that even if a target is encoded in an allocentric frame reference, this allocentric frame of reference is itself located within/ or in relation to an egocentric frame of reference. This interpretation would also permit to explain why older participants showed larger biases than younger ones. Considering that egocentric spatial memory does not decline with age, it could be that older participants relied more heavily on the egocentric coding of the target area than the younger participants which would explain the larger biases found towards the putative anchoring points of this egocentric frame of reference.

Finally, the results revealed that older participants were more variable on both the extent and the direction dimensions of the task when the remembered target was located on the right side on the computer screen rather than on its left side. This result cannot be explained by a difference in movement amplitude when the target area was presented on the right rather than on the left side of the screen because movement amplitude was exactly the same in both cases. Also, there was no difference in movement time when participants as a function of the target area at the time of recall, participants did not have to cross their midline regardless of the target area at the time of recall, and the biomechanical demands of the task were perhaps more demanding when aiming to the left rather than to the right of the computer screen.[v] Given all of the above, we have no ready explanation for this last finding.

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Footnote

[1] When the surface on which the cursor is moved is approximately at waist height as it was in the present study, movements to the right of a starting base located in front of one's midline only requires that the upper arm be rotated along its long axis. On the contrary, for movements directed to the left of the starting base, participants had to push the cursor across their body, which required a displacement of the upper arm. The mass that had to be displaced in his second case thus included that of the upper arm and increased movement inertia in comparison to the former case.

# Authors' note

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## Figure Captions

Figure 1 Variable error of aiming on the direction (upper panels) and the extent (lower panels) components of the task as a function of the age group, the target, and the recall location. Vertical lines indicate standard error of the means.

Figure 2. Constant error of aiming on the direction (upper panels) and the extent (lower panels) components of the task as a function of the age group, the target, and the recall location. Vertical lines indicate standard error of the means..

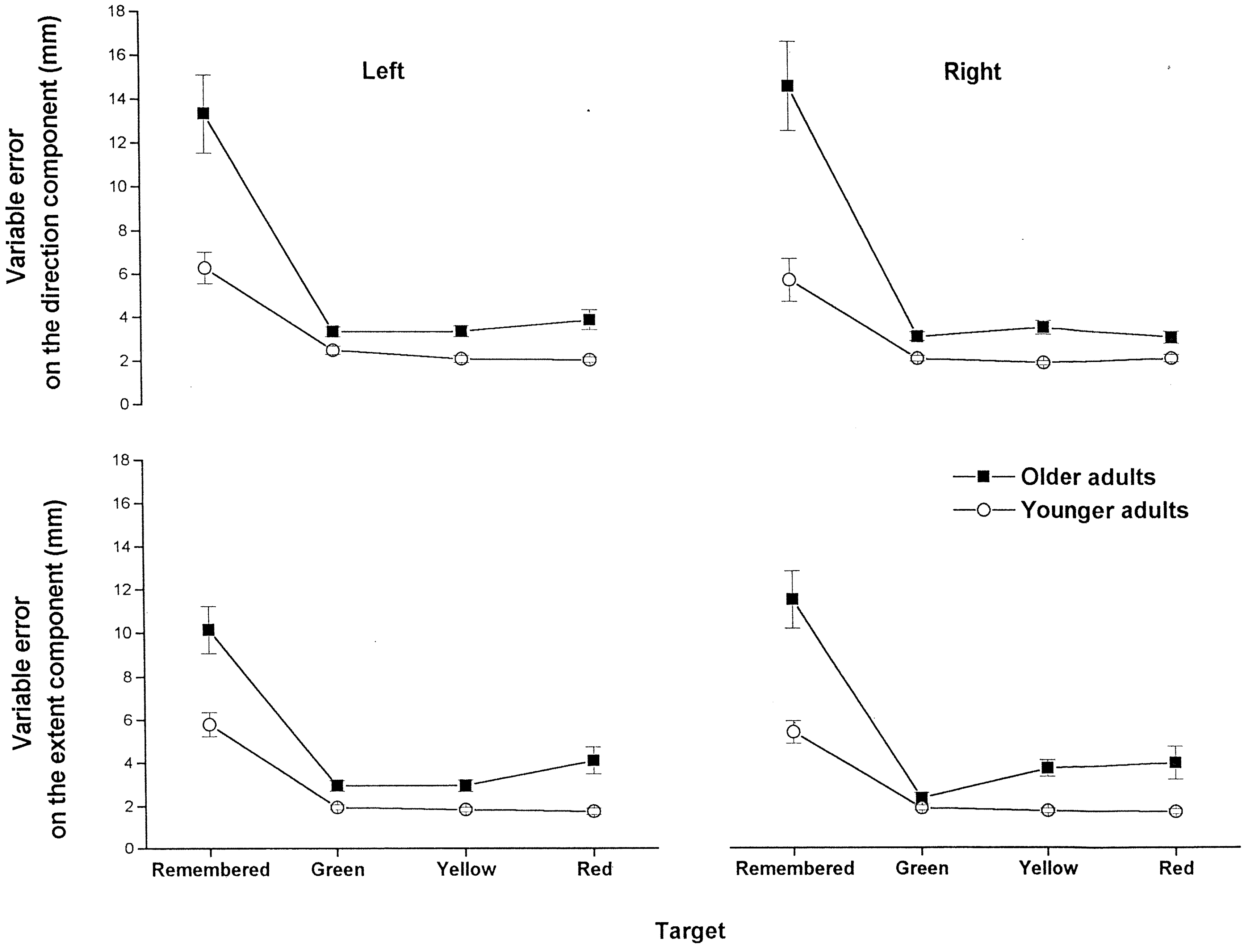
Variable error on the direction component (mm)
Variable error on the extent component (mm)
18
16
14
12
10
8
6
4
2
0
Left
Right
Older adults
Younger adults
Remembered
Green
Yellow
Red
Target

Figure 1

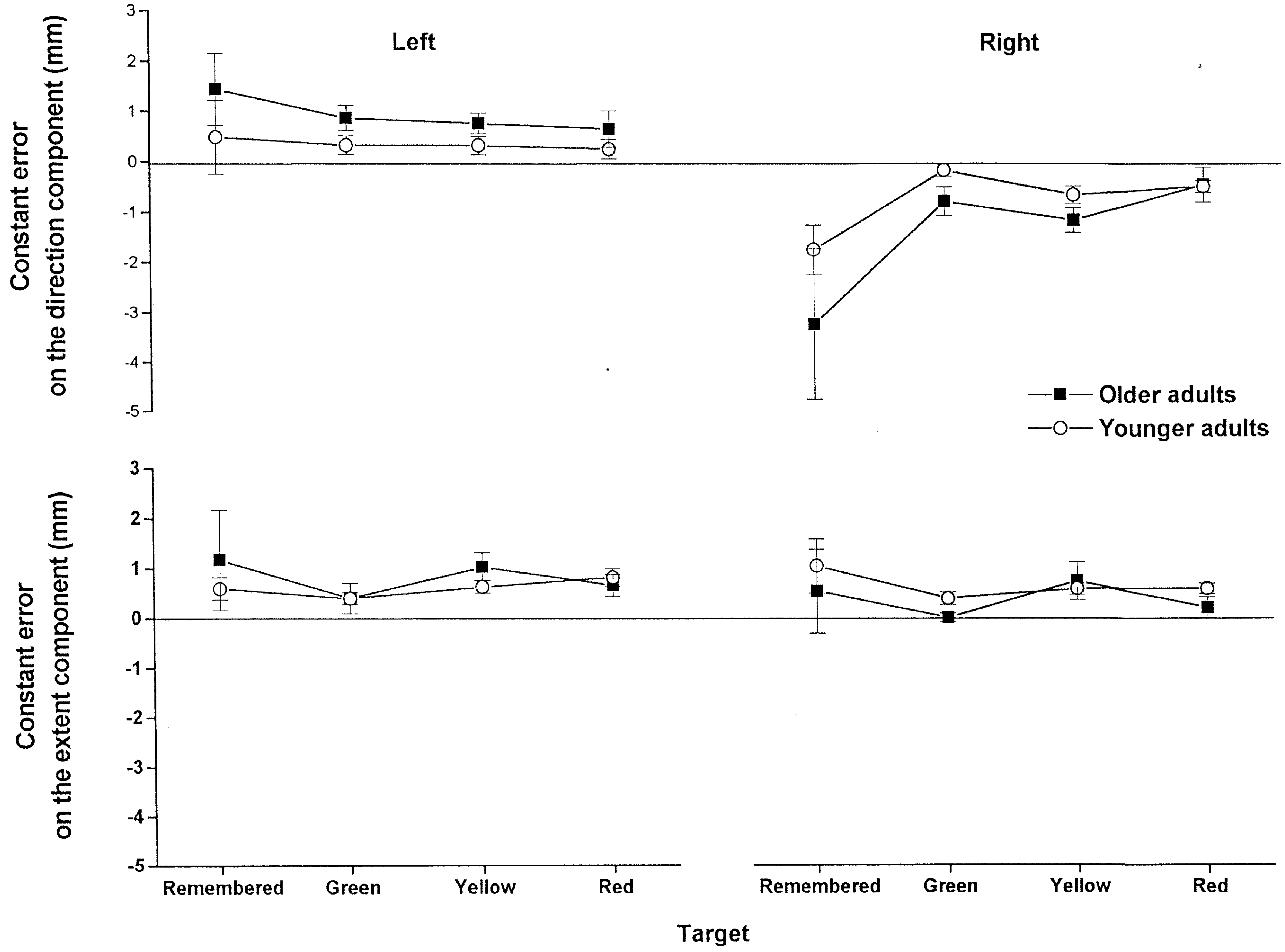
Constant error
on the direction component (mm)
3
2
1
0
-1
-2
-3
-4
-5
Left
Right
Older adults
Younger adults
Constant error
on the extent component (mm)
3
2
1
0
-1
-2
-3
-4
-5
Remembered
Green
Yellow
Red
Remembered
Green
Yellow
Red
Target

Figure 2

# CHAPITRE 6

# DISCUSSION GÉNÉRALE

# DISCUSSION GÉNÉRALE

L'exécution d'un mouvement de pointage alors que la main, la cible et le contexte visuel entourant cette cible sont visibles est habituellement très précis (Desmurget et al., 1995; Elliott et al., 1991; Proteau, 1992; Proteau & Cournoyer, 1990). Toutefois, le retrait de la vision de la main en déplacement vers la cible entraîne une augmentation de l'erreur de pointage (Carrozzo et al., 1999; Ghilardi et al., 1995; voir aussi Proteau, 1992). Lorsque le mouvement est réalisé alors que la cible n'est également plus visible, on observe une augmentation additionnelle de l'erreur de pointage (Adamovich et al., 1994 ; Darling & Miller, 1994 ; Soechting & Flanders, 1989a, b), laquelle s'accentue encore davantage en fonction de l'augmentation du délai entre la présentation de la cible et l'amorce du mouvement (Elliott & Madalena, 1987; McIntyre et al., 1998).

Le but principal de cette thèse était d'éclaircir le rôle de la mémoire lors de la planification et l'exécution d'un mouvement de pointage vers une cible qui n'est plus visible. De façon plus précise, certains facteurs pouvant améliorer ou détériorer la représentation mnésique de la cible ont été étudiés. Ces facteurs sont l'âge des participants (études 1-4), le temps de présentation visuelle de la cible (étude 1), le délai de rappel (études 1-2), la durée du mouvement de pointage (étude 2) et la présence ou non d'un contexte pendant la présentation de la cible (études 3-4). Tel que mis en lumière lors de l'introduction, ces facteurs sont parmi les plus susceptibles d'influencer l'intégrité de la représentation mnésique de la position de la cible. Par ailleurs, il s'est avéré que ces facteurs affectent non seulement la qualité mais également la nature même de la représentation mnésique de la position de la cible. Ainsi, il a été démontré que la cible pouvait être maintenue en mémoire soit sous une forme égocentrique, soit sous une forme allocentrique, et ce, en fonction des conditions expérimentales sous lesquelles se déroule le mouvement.

Dans la première section, l'impact des différents facteurs étudiés sur l'intégrité de la représentation mnésique sera analysé. Dans la même section, nous soutiendrons la proposition voulant que lors de l'exécution d'un mouvement de pointage effectué sans vision de la main vers une cible maintenue en mémoire, le maintien de cette cible s'effectue dans un cadre égocentrique (Carrozzo et al., 1999) et non pas dans un cadre de référence allocentrique. Dans cette situation, la cible serait codée dans un cadre de référence égocentrique dès sa présentation et maintenue sous cette forme pendant le délai de rappel. Les travaux réalisés lors de la présente thèse ne permettent toutefois pas de prendre position quant à la partie du corps utilisée pour localiser la cible de façon égocentrique.

## Études 1-2-3. Facteurs affectant la qualité de la représentation mnésique et évidences en faveur d'une représentation égocentrique

### Étude 1

L'un des facteurs susceptibles d'améliorer l'encodage et subséquemment le maintien de la position d'une cible en mémoire est le temps de présentation de la cible (Hanari, 1995, 1996). L'impact de ce facteur avait été démontré uniquement pour des délais de rappel très courts (500 ms) et lors du maintien de plusieurs cibles en mémoire. Nous avons donc réalisé une étude (étude 1) pour laquelle une seule cible était présentée pendant 50 ms et 500 ms et pour laquelle nous avons utilisé des délais de rappel de 0, 100, 1000 et 10000 ms. L'hypothèse de cette étude était qu'une augmentation du temps de présentation favoriserait un meilleur encodage, et par conséquent, un maintien plus durable de la position de la cible. Selon notre hypothèse, l'avantage de présenter la cible plus longtemps devait être plus profitable pour des mouvements effectués après les délais les plus longs par rapport aux délais les plus courts, ce qui devait se refléter par une interaction significative entre le temps de présentation et le délai de rappel. Tout d'abord, tel qu'attendu, le mouvement de pointage des participants était plus variable pour le délai de rappel le plus long par rapport aux délais les plus courts.[5] Ce résultat supporte de précédentes observations à ce sujet (McIntyre et al., 1997, Elliott & Madalena, 1987). Toutefois, les résultats obtenus ne supportent pas l'hypothèse voulant qu'un temps de présentation plus long favorise un meilleur encodage/maintien de la position de la cible. En effet, bien que le temps de présentation de la cible de 500 ms entraîne une erreur variable plus faible que le temps de présentation de 50 ms, on n'observe pas d'interaction entre le temps de présentation et le délai de rappel. La présentation de la cible pendant une plus longue période permettrait de localiser la cible avec plus de précision tel que proposé par Adam et al. (1995) mais ne permettrait pas de réduire l'erreur de pointage pour les délais plus longs en favorisant un encodage/maintien plus adéquat.

L'absence d'interaction entre le temps de présentation de la cible et le délai de rappel constitue une première évidence en faveur de l'hypothèse voulant que l'information soit maintenue sous un cadre de référence égocentrique. En effet, si l'information est transformée sous une forme autre que visuelle dès son retrait,

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[5] À ce titre, il importe de rappeler que l'erreur variable est considérée comme une mesure de l'oubli de l'information en mémoire (Guay, 1986 ; Guay & Hall, 1984 ; Laabs, 1973 ; McIntyre et al., 1997).

l'augmentation du temps de présentation visuelle de la cible devient alors d'aucune utilité. L'effet d'interaction entre le temps de présentation et le délai de rappel obtenu précédemment par Hanari (1995) avait probablement été causé par le fait que plusieurs cibles devaient être maintenues en mémoire simultanément. Or, dans ce cas, il est probable que la position des cibles aient été maintenue les unes en fonction des autres, soit dans un cadre de référence allocentrique plutôt que dans un cadre de référence égocentrique. Cette dernière proposition a été étudiée plus avant et confirmée dans l'étude 4 de la présente thèse.

Par ailleurs, les résultats de la première étude ont également indiqué que la variabilité du mouvement de pointage de chaque participant était plus faible pour les délais de rappel les plus courts (0, 100, 1000 ms) par rapport au délai le plus long, et ce, malgré le fait que la vitesse maximale du mouvement ait été plus élevée pour les délais les plus courts. Ce type de résultat est fort intéressant puisqu'il va à l'encontre de ce qui est habituellement observé, c'est-à-dire une augmentation de la variabilité des mouvements de pointage en fonction de la vitesse du mouvement (Meyer et al., 1982; Schmidt et al., 1979). Lors de la deuxième expérience de l'étude 1, nous avons démontré, à l'aide d'une procédure de masquage, que la présence d'une représentation iconique de la position de la cible était responsable de la chute de la variabilité pour les délais de rappel courts. Ainsi, on a observé que lorsque la cible était suivie d'un masque, la variabilité des mouvements de pointage augmentait pour les délais de rappel courts mais pas pour le délai de rappel le plus long. De plus, la vitesse maximale pour les délais de rappel courts était plus faible lorsque la cible était suivie d'un masque. En raison de la durée très courte de la persistance en mémoire de l'information iconique (moins de 300 ms ; Di

Lollo & Dixon, 1988 ; Irwin & Yeomans, 1986 ; Kihutchi, 1987), les participants augmenteraient la vitesse à laquelle ils exécutent leur mouvement afin de profiter de la représentation iconique de la position de la cible. L'étude 1 soutient la proposition d'Elliott et Madalena (1987) voulant que le maintien d'une représentation iconique de la cible permette d'améliorer la précision du mouvement de pointage. De plus, nous avons démontré que l'utilisation de la mémoire iconique entraîne des changements au niveau de la cinématique du mouvement de pointage. Les participants augmentaient la vitesse de leur mouvement pour profiter de la persistance visuelle de la cible.

L'augmentation de l'erreur variable de pointage en fonction de l'augmentation du délai de rappel est tout à fait compatible avec l'idée voulant que la cible mémorisée soit maintenue dans un cadre de référence égocentrique. En effet, il a été démontré à quelques reprises que l'information proprioceptive sur laquelle est basée un cadre de référence égocentrique est sujette à se détériorer avec le temps (Vindras et al. , 1998; Wann & Ibrahim, 1992 ; voir toutefois, Desmurget, Vindras, Gréa, Viviani, & Grafton, 2000). Toutefois, tel que démontré précédemment, la présence d'une représentation iconique de la cible permet également d'expliquer la variabilité plus faible observée pour les délais courts.

Finalement, sur la seule base de l'étude 1, il était difficile de déterminer si la représentation iconique remplaçait la représentation égocentrique du mouvement ou *l'accompagnait* pour les délais de rappel courts. La deuxième étude a permis de répondre à cette question.

## Étude 2

Pour la deuxième étude, nous avons vérifié l'hypothèse voulant que l'augmentation du temps de mouvement puisse causer une dégradation de la représentation mnésique de la cible, tel qu'observé par le biais de l'effet de distance. Cet effet est obtenu lorsqu'une l'augmentation de la distance à parcourir entre la base de départ et la cible entraîne une détérioration de la représentation mnésique de la cible, tel qu'indexé par une augmentation de la variabilité inter-essais de pointage. Étant donné que l'atteinte des cibles éloignées s'accompagne d'une augmentation du temps de mouvement, nous avons proposé que cette augmentation du temps de mouvement puisse être responsable de l'effet de distance.

Cette hypothèse a été vérifiée lors de la première expérience de l'étude 2. La moitié des participants devaient alors atteindre les cibles rapprochées dans un temps de mouvement plus long que les cibles rapprochées, ce qui devrait inverser l'effet de distance défini ci-haut. L'autre moitié des participants effectuait le mouvement de pointage sans contrainte de temps, ce qui devait résulter en un effet de distance classique. L'amorce du mouvement de pointage s'effectuait après un délai de rappel de 100 ms ou de 10000 ms. Un effet de distance a été observé pour le groupe qui réalisait le mouvement de pointage sans contrainte temporelle particulière, et ce, pour les deux délais de rappel. Toutefois, pour les participants qui devaient atteindre les cibles rapprochées dans un temps de mouvement plus long que pour les cibles éloignées, l'effet de distance a été inversé, c'est-à-dire que la variabilité du mouvement de pointage était plus élevée pour les cibles rapprochées que pour les cibles éloignées, et ce, pour les deux délais de rappel. L'effet de distance ne peut donc pas être causé par la distance qui sépare la cible de la base de départ ou par la vitesse de mouvement plus élevée normalement retrouvée pour les mouvements de plus grande amplitude. De plus, nous avons clairement démontré que l'erreur n'était pas causée simplement par le passage du temps. En effet, une augmentation du temps de mouvement d'environ 300 ms, notée entre l'atteinte des cibles rapprochées et éloignées, a entraîné une erreur variable de pointage environ deux fois plus élevée que le fait d'attendre pendant 10 secondes sans bouger.

Lors de la deuxième expérience de l'étude 2, nous avons démontré que l'effet de distance prend place uniquement pour les mouvements de pointage dirigés vers une cible maintenue en mémoire et non pour les mouvements de pointage dirigés vers une cible visible. Sur la base de ces résultats, nous avons proposé que l'exécution du mouvement de pointage interfère directement avec la représentation mnésique de la position de la cible. Cette proposition a été soulevée à plusieurs reprises dans le passé (voir Logie, 1995, pour une revue). Selon Logie, (1995), le mouvement fait appel à des processus également impliqués lors du maintien et/ou du rafraîchissement de l'information en mémoire, nuisant ainsi à son bon fonctionnement. Dans cette étude, nous avons démontré que la réalisation du mouvement de pointage vers une cible interférait avec le maintien de la représentation mnésique de cette même cible.

De plus, le fait que l'effet de distance prenne place de façon similaire pour des délais court et long supporte l'idée que la cible est maintenue dans un cadre de référence unique (égocentrique) peu importe le délai de rappel. Dans l'éventualité où la cible serait maintenue uniquement dans un cadre de référence allocentrique (ou selon une représentation iconique) pour un délai court et dans un cadre égocentrique pour un long délai, nous aurions du observer que l'effet d'interférence différait selon le format de remisage l'information. Or, tel ne fut pas le cas.

Enfin, l'effet de distance peut également être considéré en lui-même comme une évidence en faveur de l'idée voulant que l'information relative à la localisation de la cible est maintenue dans un cadre de référence égocentrique. En effet, l'exécution d'un mouvement est davantage susceptible d'interférer avec une représentation égocentrique de la position de la cible parce que cette dernière est basée sur les mêmes ressources (ou modalités sensorielles) que le mouvement. Tel sera particulièrement le cas si la représentation égocentrique est centrée sur le bras ou la main qui exécute le mouvement (Carozzo et al., 1999 ; Chieffi et al., 1999 ; Flanders et al., 1992 ; Gordon et al., 1994 ; Meegan & Tipper, 1998 ; Rossetti et al., 1995 ; Vindras & Viviani, 1998). Toutefois, le maintien d'une représentation visuelle ou allocentrique de la position de la cible apparaît peu susceptible de subir l'interférence du mouvement (voir Logie (1995) pour une proposition similaire) parce que basés sur des ressources différentes.

## Étude 3

Finalement, un dernier facteur susceptible d'influencer la représentation mnésique d'une cible a été évalué. Cette étude a été réalisée pour déterminer l'impact du contexte visuel sur le mouvement de pointage dirigé vers une cible maintenue en mémoire iconique (délai de rappel de 100 ms). Nous avons choisi d'étudier l'influence du contexte pour des délais très courts puisqu'il s'est avéré que le contexte avait un impact limité pour des délais plus longs (2-4 secondes ; Barry et al., 1997). Nous voulions ainsi déterminer si la présence du contexte en mémoire iconique était susceptible d'améliorer le maintien de la position de la cible, et par le fait même diminuer la variabilité du mouvement de pointage.

Lors de cette troisième étude, la cible était présentée avec ou sans contexte visuel, lequel consistait en une série de traits verticaux illustrés sur la surface de travail. La cible et le contexte étaient visibles lors de la réalisation du mouvement de pointage pour la moitié des essais. Toutefois, le déplacement du curseur manipulé par le participant n'était jamais visible. Les résultats ont indiqué que le mouvement de pointage vers les cibles rapprochées était biaisé vers la gauche alors que pour les cibles éloignées, le mouvement était biaisée vers la droite. Ces biais ont été obtenus peu importe que la cible soit visible ou non pendant l'exécution du mouvement de pointage. Ce résultat supporte l'idée voulant que le type de contexte utilisé dans cette étude modifie l'estimation de la distance séparant la base de départ de la cible (Coello & Magne, 2000). De plus, puisque les effets du contexte prenaient place dès la fin de la première impulsion du mouvement, il apparaît que le contexte visuel affecte principalement la planification du mouvement. De façon plus importante, la présence d'un contexte visuel n'a pas permis de diminuer l'erreur variable par rapport à une situation où le contexte n'était pas présent. Sur la base de ce dernier résultat, on peut affirmer que le contexte ne favorise pas une meilleure représentation de la cible en mémoire, du moins pour les délais de rappel courts. Cet aspect des résultats supporte de façon indirecte l'idée que la représentation de la cible utilisée pour le mouvement est encodée dans un cadre de référence égocentrique. En effet, la variabilité du mouvement semble être imperméable à une source enrichie d'information visuelle (i.e., le contexte utilisé), ce qui suggère qu'une information de nature allocentrique ne favorise pas le maintien et le rappel de la position de la cible.

L'étude 3, tout comme les deux études précédentes, a été effectuée avec la participation de jeunes adultes et de personnes âgées. Or, dans chacune de ces études, la précision et la variabilité du mouvement de pointage des jeunes adultes et des personnes âgées étaient fortement similaires. Tel que démontré précédemment, le maintien de l'information relative à la position de la cible semble s'effectuer dans un cadre de référence égocentrique. Or, il a été proposé que chez la personne âgée, le maintien de l'information égocentrique en mémoire est préservé alors que le maintien de l'information allocentrique deviendrait moins efficace (Desrocher & Smith, 1998). Ceci constitue une dernière évidence, cependant indirecte, en faveur de l'hypothèse voulant que la position de la cible soit maintenue dans un cadre de référence égocentrique lors de l'exécution d'un mouvement de pointage exécuté vers une cible maintenue en mémoire.

## Conclusion des études 1 à 3

En bref, dans les trois premières études de cette thèse, un seul facteur a été identifié, de façon indirecte, comme améliorant le maintien en mémoire de la position de la cible, soit la présence d'un délai de rappel court (moins d'une seconde). Par contre, deux facteurs ont affecté l'intégrité de la représentation mnésique de la position de la cible, soit l'augmentation du délai de rappel et l'effet de distance (ou l'augmentation du temps de mouvement). Le temps de présentation de la cible et la présence ou non d'un contexte visuel riche n'ont pas affecté la qualité de la représentation mnésique de la cible, probablement parce que l'information est maintenue dans un cadre de référence égocentrique. En ce sens, nous appuyons la proposition de Bédard et Proteau (sous presse) voulant que la cible soit codée dans un plan intrinsèque (ou égocentrique) lorsque la position de départ de la main n'est pas fovéalisée avant l'amorce du mouvement, comme c'était le cas pour les études présentées dans cette thèse.

De plus, nous avons démontré que les personnes âgées sont en mesure d'utiliser l'information proprioceptive lors de la formation de la représentation égocentrique et de son maintien en mémoire de façon aussi efficace que les jeunes adultes. À première vue, ce résultat peut paraître surprenant compte tenu des déficits des personnes âgées au niveau du traitement de l'information proprioceptive (Warabi et al., 1986 ; Chaput & Proteau, 1996 ; Proteau et al., 1994). Plusieurs aspects peuvent toutefois avoir contribué à atténuer les déficits proprioceptifs des personnes âgées. Premièrement, il importe de spécifier que les personnes âgées ayant participé aux expériences de la présence thèse sont très actives physiquement. De plus, l'espace de travail sur lequel les tâches étaient effectuées était réduit et le temps de mouvement alloué pour effectuer la tâche n'était pas contraint, ce qui avait pour conséquence de faciliter la réalisation de la tâche. D'autre part, il est à noter que la variabilité intra-participant était plus élevée chez les personnes âgées que chez les jeunes adultes. Cette variabilité plus élevée peut avoir masqué certaines différences entre les deux groupes d'âge. Malgré cela, les résultats obtenus lors des trois premières études concordent avec l'idée voulant que le maintien de l'information dans un cadre de référence égocentrique ne soit pas affecté avec l'âge (Desrocher & Smith, 1998, 1999).

Enfin, bien que la cible soit maintenue sous un format égocentrique, cela n'empêche pas que l'information puisse également être maintenue sous une autre forme. Au niveau des délais inférieurs à une seconde, il a déjà été démontré qu'une représentation iconique de la cible est utilisée, probablement afin de mettre à jour la représentation égocentrique. En ce qui a trait au délai long, il est également possible qu'une représentation visuelle (plus abstraite que la représentation iconique) soit également utilisée. De plus amples recherches sont nécessaires sur le sujet.

## Encodage et maintien d'une cible dans un cadre de référence allocentrique et vieillissement

### Étude 4

Les études 1, 2 et 3 ont indiqué que les personnes âgées étaient en mesure de maintenir l'information égocentrique de façon aussi efficace que les jeunes adultes. La dernière étude avait pour but de vérifier si le maintien en mémoire de la cible sous un format allocentrique est affecté chez la personne âgée tel que proposé par Desrocher et Smith (1998). Pour ce faire, quatre cibles étaient présentées pendant 1000 ms à des jeunes adultes et à des personnes âgées. Après un délai de rappel de 10 secondes, trois des quatre cibles étaient présentées à un endroit différent de leur présentation initiale. Les participants devaient alors atteindre tour à tour la cible manquante puis les trois cibles toujours visibles. Contrairement aux trois premières études, le mouvement du curseur manipulé par le participant était visible afin d'éviter que ceux-ci aient à transférer la position de la cible dans un cadre égocentrique (Soechting & Flanders, 1989a, b). Les résultats ont démontré que les mouvements de pointage des personnes âgées étaient plus variables que ceux des jeunes adultes pour l'atteinte des quatre cibles. Toutefois, l'écart entre les deux groupes d'âge était significativement plus grand pour la cible mémorisée que pour les cibles toujours visibles. Ce résultat confirme la présomption de Desrocher et Smith (1998) voulant que le maintien de l'information allocentrique soit déficitaire avec l'âge. De plus, nous démontrons que ce déficit a un impact direct sur la réalisation d'un mouvement de pointage.

Dans le futur, il pourrait être intéressant de déterminer si l'augmentation du temps de présentation de la cible et/ou la présence d'un contexte fixe serait susceptible d'améliorer la représentation allocentrique de la position de la cible chez les jeunes adultes et les personnes âgées. Il pourrait aussi être intéressant de vérifier si l'effet de distance prend place lorsque la cible est maintenue dans un cadre de référence allocentrique. Dans un tel cas, le maintien de la position de la cible dans un cadre de référence faisant appel à des ressources différentes de celles utilisées par le mouvement pourrait permettre d'éliminer l'effet de distance.

## Conclusion

La présente thèse révèle que le maintien d'une seule cible s'effectue dans un cadre égocentrique. Nous appuyons en ce sens les propositions de McIntyre et al. (1998 ; Carrozzo et al., 1999). Cette thèse ne permet toutefois pas d'identifier la partie du corps par laquelle la cible est maintenue. Toutefois, nous démontrons que la représentation égocentrique de la cible n'est pas affecté par le temps de présentation de la cible ou l'âge des participants. Toutefois, l'augmentation du temps de mouvement et dans une moindre mesure l'augmentation de la durée du délai de rappel sont susceptibles d'affecter l'intégrité de la représentation égocentrique de la position de la cible. Par ailleurs, la formation de la représentation égocentrique est affectée par la présence d'un contexte visuel, mais celui-ci ne permet pas d'améliorer le maintien de l'information, du moins pour des courts délais de rappel. Enfin, nous avons démontré que le maintien de l'information allocentrique est affecté avec l'âge.

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