Aging and Motor Control

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The goal of the two experiments of the present study was to determine whether in an aiming task performed within a relatively long movement time (MT) bandwidth, older adults make similar use of visual information for motor control as younger adults. Older and younger subjects practiced a manual aiming task toward one (Experiment 1), or one of many (Experiment 2) small target(s) while only the target to be reached was visible (proprioception only: P) or under normal lighting condition (proprioception + vision: PV). Following practice, all subjects were transferred to the P conditions. The results of both experiments indicate that the older subjects were, during practice, as accurate as the younger ones in the PV condition. Moreover, both groups suffered a large and similar increase in aiming error in the transfer condition. This suggests that older adults process the sensory information available in that type of task similarly to younger subjects but at a lower speed. However, when the temporal constraints of the task are stringent, older adults might rely more on modes of control in which sensory information plays a minimal role when compared to younger subjects. Finally, the results of the second experiment suggest that, when multiple targets are used, older adults appear to program a response which is optimally suited for a “central” target.

Each day we must touch or grasp things that are located in our environment. Yet, we still do not fully understand the processes underlying the expertise and near flawless performance shown in these everyday life situations. Generally, it is thought that practice results in the development of a sensorimotor store which can be used in the control of movement. The way in which control is exerted involves recognition of feedback arising from the ongoing movement, which in turn allows anticipation of the movement consequences associated with it (Abbs, Gracco, & Cole, 1984; Bullock & Grossberg, 1988, 1991; Meyer, Abrams, Kornblum, Wright, & Smith, 1988; van der Meulen, Gooskens, Denier van der Gon, Gielen, & Wilhelm, 1990). This predictive process provides the performer with information about potential errors and allows corrective actions to be carried out before deleterious effects become manifest. In terms of this type of control model, one can ask what sources of afferent information are used to guide an ongoing movement as well as whether their utilization remains unchanged across one’s life.

It has been shown that aging brings a general decrease in the accuracy of sensory organs (Fozard, 1990) as well as in the speed with which one can process information (Salthouse, 1982). Much less information is available on the modifications that may occur as a result of aging on the control processes one uses to guide his/her movement toward a discrete target. It is known that aiming movements are performed more slowly by older than younger adults (Pratt, Chasteen, & Abrams, 1994; Warabi, Noda, & Kato, 1986) and that the former make more corrective submovements in the decelerative phase of the movement (Goggin & Meeuwen, 1992; Pratt et al., 1994). This has been interpreted as evidence of greater caution to the accuracy rather than the speed of movement by older adults (Rabbitt, 1979) but also of the relative inaccuracy of motor control processes of older adults when compared to younger ones (Chaput & Proteau, 1996; Pratt et al., 1994). Still, we know little about the role played by different sources of afferent information for fine motor control.

We (Chaput & Proteau, 1996; Proteau et al., 1994) have recently gained some information in that regard by having older and younger subjects practice a manual aiming movement while different sources of afferent information were available. One group of subjects performed the task in a condition in which only the target to be reached was visually available (condition proprioception only: P) while a second group of subjects performed the task under normal visual conditions (condition proprioception + vision: PV). Each trial was followed with knowledge of results (KR) regarding the subjects’ aiming accuracy at the preceding trial. Following their respective practice, all subjects were submitted to a transfer test in which only the target to be reached was visually available and no KR was provided. As expected, the younger subjects were more accurate during acquisition than their older counterparts (Pratt et al., 1994). Moreover, the results confirmed previous observations in showing that the PV condition led to more accurate movements than the P condition. This suggested that the sensorimotor control processes of older subjects are less accurate than those of younger subjects and that a combination of visual and proprioceptive afferent information is a more efficient source of control than proprioceptive information alone, regardless of the age group.

In transfer, withdrawing KR had no effect per se on movement accuracy whereas withdrawing vision caused, for the older subjects, an increase in aiming error to the level of that observed for those subjects who had trained in the P condition. This increase in error in the transfer condition was much larger for the younger subjects, who became less accurate than their older counterparts, or than novice subjects, who performed the task in the P condition without KR. This suggested that the role played for motor
control by the different sources of afferent information available while practicing the task was much different between the two age groups.

For the younger subjects, it has been suggested (see Proteau, 1992 for a review) that a major characteristic of motor learning is its relative specificity to the feedback sources available when it occurred (see also Gibson, 1979 for a similar proposition). Hence, withdrawing or even adding (Elliott & Jaeger, 1988; Proteau, Marteniuk, & Lévesque, 1992) a source of afferent information after a period of practice where it was either present or absent results in a deterioration in movement accuracy. This specificity hypothesis was based on the proposition that early in the learning of a task, the different sources of afferent information used to control the ongoing movement are compared intramodally (for example: visual afferent information to visual expected sensory consequences) to some internal representation of the movement. However, as practice increases, we have suggested that the different sources of available sensory information are compared to an integrated or intermodal representation of the expected sensory consequences. This was supported by results showing that for young adults, the withdrawal of one source of afferent information used for movement control was more detrimental after extensive practice than it was after modest practice (see Proteau, 1992).

The results obtained for the older subjects in our previous work showed that withdrawing vision of their moving limb caused them to perform exactly as individuals who practiced in the P condition. We took this result as evidence that no integration took place for the older subjects between visual and proprioceptive afferent information during acquisition. Hence, withdrawing visual information made the older subjects revert from visual to proprioceptive information as the main input for the control of their movement, which would explain why, in transfer, they performed as well as subjects who had practiced in the P condition.

However, this interpretation is challenged by data reported by Teasdale, Stelmach, Breunig, and Meeuwsen (1991) for postural control. These authors showed that when a subject is asked to stand still, both older and younger individuals suffer an increase in sway following withdrawal of visual information (eyes closed). Moreover, after a long period with their eyes closed, the older subjects had a larger sway dispersion than younger subjects. When asked to open their eyes, the younger subjects were able to adapt rapidly to the addition of visual information and reduced their sway to normal dispersion. However, this was not the case for the older subjects, who exhibited an increased sway dispersion. This result was taken as evidence that, on top of having reduced peripheral sensibility, the older subjects had great difficulty in integrating the newly available visual information to that which has been used to maintain postural control in the absence of vision (namely proprioceptive and vestibular inputs). They suggest that aging does not necessarily result in an independent processing of the various sources of sensory information but rather in a deficit of central integrative mechanisms (Teasdale et al., 1991).

There are numerous differences between the task used by Teasdale and his co-workers and that used in our previous work. For instance, postural control might be seen as a rather gross motor skill, while our task was clearly a fine motor skill. In the same vein, postural control is largely proximal, whereas our task had an important distal component. In postural control the role played by vision is largely that of exproprioception (Lee, 1980), whereas in our work it guides movement toward the target. Finally, and we think more importantly, in Teasdale’s work the task was such that the subjects had a rather long period of time to process the various sources of sensory information available. In our work, subjects were required to complete their movement in a mean time of approximately 500 ms. Although this delay leaves enough time for the utilization of visual information for movement control, as shown by the fact that the PV condition led to better accuracy than the P condition during acquisition, it might be that this delay was too stringent for the older subjects to use it in the same manner as younger subjects. In fact, it might be that this short delay encouraged the older subjects to preplan more thoroughly their movement prior to its initiation in order to rely less on on-line control. If such was the case, it would explain why the withdrawal of visual information in the transfer test had less detrimental effect on the older than the younger subjects. The former relied less on that information for on-line control and, thus, its withdrawal had less severe consequences. The goal of the present study was to test this hypothesis. To reach that goal, we submitted older and younger subjects to the same experimental protocol as in our previous work. However, subjects were required to complete their movements in a delay ranging between 850 ms and 950 ms. The above-developed hypothesis would be supported if the withdrawal of visual information had the same deleterious effect on the subjects of both age groups.

**Experiment 1**

**METHOD**

**Subjects**

Thirty-one healthy, self-declared right-handed subjects participated in this study. All subjects had normal or corrected to normal vision. Moreover, before starting data collection, the experimenter made sure that all subjects were able to see the targets used in the different conditions of acquisition and transfer. No subjects were discarded on the basis of that screening procedure. Fifteen of these subjects were aged between 65 and 80 years old (mean of 73.8, SD = 5.74). They were recruited on a voluntary basis from a pool of regular participants in the social activities of an association of retired workers from the Montréal area. They were all living on their own and all reported having good health. Moreover, each of these subjects performed the DSST (Digit Symbol Substitution Test), an abridged version of the Weschler Adult Intelligence Test. The results of this test indicated that all subjects were representative of their age group (M = 46.3, SD = 5.5). The remaining 16 subjects were undergraduate students in the Department of Physical Education at the Université de Montréal. They were aged between 19 and 28 years old (mean of 21.4, SD = 3.47) and volunteered from introductory psychomotor behavior
Subject’s Task and Apparatus

The subject’s task was to make target pointing movements with a stylus from a start position to the target to be reached. These aiming movements were made with the subject’s nonpreferred left hand. We asked the subjects to use their nonpreferred hand to increase the probability that practice results in learning of the task. The apparatus was situated on top of an ordinary table directly in front of a seated subject. It consisted of three elements: (a) a stylus, (b) a defined start position, and (c) the target to be reached. The stylus was 16 cm long and weighed 35 g. The starting position was defined by a small hole (4 mm in diameter) made on the tabletop. Placing the stylus in that hole depressed a micro-switch which, when released, indicated movement initiation. The starting position was located approximately in line with the subject’s left shoulder, while the target was placed directly in line with their sternum. The distance between the starting position and the target remained fixed at 30 cm. The target was provided by the filtered (red) light of a small optical fiber (1 mm in diameter) visible through a thin sheet of black Plexiglas placed atop a digitizing table (Summagrid III from Summagraphics Inc.; accuracy of .0127 mm and sampled at 100 Hz). Subjects started their movement by lifting the stylus from the starting position. The spatial accuracy of each movement was defined as the distance (both amplitude and direction) between the target and the first contact registered between the stylus and the Plexiglas covering the digitizing table. Also, leaving the starting base triggered a millisecond timer, which was stopped when the stylus hit the Plexiglas, thus defining the subject’s movement time (MT).

Procedure

The subjects were instructed to produce a left-handed aiming movement toward the target in an MT ranging from 850 to 950 ms. Movements were to be completed spatially as accurately as possible while being completed within the MT bandwidth. A goal MT was used to facilitate our interpretation of the spatial accuracy data by reducing the possibility of different speed-accuracy trade-offs (Fitts, 1954; Schmidt, Zelaznik, Hawkins, Frank, & Quinn, 1979) for the different age groups (Goggin & Meeuwse, 1992; Warabi et al., 1986).

The subjects of each age group were divided into two different groups of 8 subjects each (only 7 older subjects for the P condition). The subjects of all groups were trained at the experimental task for 200 trials. For each age group, the subjects performed the task under one of two conditions of acquisition: PV and P. For the PV (proprioception + vision) condition, the task was performed under normal lighting conditions so that the subjects could see their aiming hand from start to finish. In the P (proprioception) condition, the lights of the experimental room (a dark room) were turned off so that only the target to be reached was visually available. Under the P condition, hitting the digitizing table turned on a 40-watt lamp in the experimental room. Thus, all subjects were permitted to see where the stylus landed relative to the target. Further, following each trial, the experimenter provided verbal KR regarding MT (in ms). Once KR had been provided, and approximately 2 sec following movement completion, the subjects put the stylus back on the starting base which, for the P condition, caused the lights of the experimental room to be turned off (decay time of 60–65 ms). After waiting a period of approximately 2 sec, the experimenter indicated to the subject that he/she could initiate a new trial. Following the last acquisition trial, all subjects were submitted to a 40-trial transfer test using the P condition with no KR. The lights of the experimental room were turned off for the duration of the transfer test.

Different dependent variables were analyzed to summarize the subjects’ performances. First, because we asked the subjects to complete their movement within a time bandwidth, we used the mean MT to describe the temporal component of the task. Second, because the root mean square error (RMSE) is thought to represent the best overall measure of performance accuracy (Henry, 1975) and captures simultaneously the subjects’ response bias and variability, this dependent variable was compartmented for each successive block of 10 trials for both the amplitude and the direction error of the subjects’ movement (frontal and sagittal axes of the movement, respectively).

RESULTS

Acquisition

The data collected for each dependent variable during acquisition were submitted individually to a 2 age group (older vs younger) × 2 conditions of acquisition (PV vs P) × 20 blocks of trials (1–10; 11–20, . . . 191–200) ANOVA with repeated measures on the block factor.

Movement amplitude. — Figure 1 (left panel) shows that the subjects of both age groups were equally accurate in the PV condition (mean of 2.69 and 3.26 mm for the younger and older subjects, respectively). They were both also more accurate in the PV than in the P condition. However, the increase in error noted in the P condition was significantly larger for the older than the younger subjects (15.49 mm vs...
Movement direction. — The same pattern of results as that reported for movement amplitude was also obtained for movement direction. As illustrated in the right panel of Figure 1, both age groups were equally accurate when performing the task in the PV condition (mean of 2.53 and 3.19 mm for the younger and older subjects, respectively). However, although performing the task in the P condition caused an increase in error for both the younger and the older subjects (4.31 mm vs 10.3 mm, respectively), it was significant only for the latter group. This is supported by a significant age group × conditions of acquisition interaction, $F(1,27) = 10.64, p < .05$.

Movement time. — As illustrated in Figure 2 (top panel), as a group, the subjects were successful in performing movements which were completed within the prescribed bandwidth. Nonetheless, we noted a significant age group × conditions of acquisition interaction, $F(1,27) = 6.01, p < .05$. This interaction indicates that the younger subjects performed the task in the same delay, regardless of the condition of acquisition (889 ms and 905 ms, for the PV and P condition, respectively), whereas the older subjects took less time in the P than in the PV condition (870 ms vs 899 ms). Concerning within-subject variability, Figure 2 (middle panel) shows that, for the first block of acquisition, the older subjects were more variable in their MT than the younger subjects (215 ms vs 131 ms, respectively). However, this variability decreased rapidly, and by the second block of trials, no differences were noted between the age groups. This is supported by an age group x blocks of trials interaction, $F(1,27) = 2.76, p < .05$. Finally, the lower panel of Figure 2 illustrates the between-subject variability. Although no statistical analysis can be computed on these data (only one score for each cell), it is clear that the different experimental conditions led to a similar between-subject dispersion.

Acquisition vs Transfer

The effect of withdrawing visual information was evaluated by comparing the subjects’ performance obtained late in acquisition (last 40 trials) and in transfer. The data collected for each dependent variable were submitted individually to a 2 age group (older vs younger) × 2 conditions of acquisition (PV vs P) × 2 experimental phases (acquisition vs transfer) ANOVA with repeated measures on the last factor.

Movement amplitude. — As illustrated in Figure 1 (left panel), the passage from acquisition to transfer resulted in a significant condition of acquisition × experimental phase interaction, $F(1,27) = 10.28, p < .05$. Specifically, withdrawing only KR in transfer had minimal and not significant effect on aiming accuracy. This is illustrated by the fact that the subjects who trained in the P condition, regardless of the age group, performed similarly late in acquisition and in the transfer test, $F < 1$. On the contrary, withdrawing vision in transfer had a deleterious effect on aiming accuracy, $p < .05$. In fact, the subjects of both age groups were similarly affected by the withdrawal of visual information and became less accurate than the subjects who had trained in the P condition.

Movement direction. — The results illustrated in Figure 1 (right panel) are largely similar to those reported above. Again, the passage from acquisition to transfer resulted in a significant condition of acquisition × experimental phase interaction, $F(1,27) = 9.55, p < .05$. As was the case for movement amplitude, the subjects who trained in the P condition, regardless of the age group, performed similarly
late in acquisition and in the transfer test, $F < 1$. Also, withdrawing vision in transfer had a deleterious effect on aiming accuracy, $p < .05$.

Movement time. — As illustrated in Figure 2, the passage from acquisition to transfer resulted in a significant age group $\times$ experimental phases interaction, $F(1,27) = 6.1$, $p < .05$. This interaction indicates that the younger and the older subjects had similar mean movement time in the four last blocks of acquisition (909 ms vs 886 ms), $F < 1$. However, in transfer, the older subjects had somewhat longer mean movement times than the younger subjects (960 ms vs 899 ms, respectively), $F(1,54) = 6.09$, $p < .05$. The passage from acquisition to transfer also resulted in a significant conditions of acquisition $\times$ experimental phases interaction, $F(1,27) = 4.93$, $p < .05$. As illustrated in Figure 2, the mean movement time in acquisition was equivalent for the subjects who trained in PV and in the P condition (896 ms vs 898 ms), $F < 1$. However, mean movement time increased in transfer for the subjects who had trained in the P condition but not for those who had trained in the PV condition (967 ms vs 892 ms), $F(1,54) = 9.23$, $p < .05$. Concerning MT within-subject variability, Figure 2 shows an interaction between the age groups and the experimental phases, $F(1,27) = 7.96$, $p < .05$. This interaction indicates that the two age groups were equally variable for the last four blocks of acquisition (83 ms vs 85 ms for the younger and older subjects, respectively). However, in transfer, the older subjects were more variable (130 ms) than their younger counterparts (86 ms). This was particularly the case for the first two blocks of transfer.

DISCUSSION

The goal of the present experiment was to determine whether the withdrawal of visual information, which had been available during the practice of a manual aiming movement, would have a similar effect on movement accuracy of younger and older subjects, when the time allowed to complete their movement was relatively long. The results of the acquisition phase indicated that the movement time bandwidth used in the present study was near-optimal to reach the goal of the present study. Specifically, this MT permitted the older subjects, during the acquisition phase of the experiment, to be as accurate as younger subjects in the PV condition. Therefore, the likelihood that the imposed MT bandwidth provided the older subjects with enough time to process optimally the information available to control their movement was very high.

A very different pattern was found for the subjects who performed the acquisition phase of the experiment in the P condition. For this condition, the older subjects were less accurate than the younger ones. Moreover, no improvement was noted over the 200 acquisition trials. This difference between the older and younger subjects could not be associated with the older subjects finding it difficult to process the posttrial feedback (KR) in order to improve their aiming accuracy. This is the case because Swanson and T. D. Lee (1992) have recently shown that both groups of subjects were equally able to process knowledge of results to improve their performance. Rather, these results suggest that the sensorimotor interface of older subjects, when based on proprioceptive information, is less accurate than that of younger subjects (Chaput & Proteau, 1996; Proteau et al., 1994; Teasdale et al., 1991). Also, because the older and younger subjects were equally accurate in the PV condition, we can conclude that the weak link (sensory vs motor) of the interface is sensory in nature. This supports previous work showing that in a task that does not require a vast amount of force, performance decrement is generally caused by a loss of sensitivity of the different senses (Johnson, Miao, & Sedum, 1987; Jordan, 1978; Meeuwsen, Sawicki, & Stelmach, 1993; Rosenhall & Rubin, 1975; Stelmach & Sirica, 1986).

More importantly in the framework of the present study, the results indicated that the withdrawal of the visual information available during acquisition had a deleterious effect on aiming accuracy. In our previous work (Chaput & Proteau, 1996; Proteau et al., 1994), this pattern of results had only been noted for the younger subjects, whereas in the present study, both age groups were affected similarly. The only difference between our previous work and the present study concerned the imposed MT bandwidth within which the subjects were encouraged to complete their movement (450–550 ms in our previous work and 850–950 ms in the present study).

Experiment 2

Because the results of this first experiment were, on an absolute basis, contrary to those of our previous work, we felt that they needed to be replicated. This was the first objective of the present experiment. As a second objective we wanted to determine whether the same pattern of results would be obtained if multiple targets were used. When practicing the task in the PV condition, the subjects’ aiming movements are relatively stable and follow a very similar trajectory from trial to trial. Therefore, one might argue that the “explored” area is very much constrained. If, as suggested before (Ghez, 1992, 1995), proprioceptive information is easily decalibrated in the absence of visual information, one might argue that withdrawing vision in transfer made the subjects drift away from that preferred trajectory and, as a consequence, left them without any reference to guide their movement except that available from seeing the target. Using multiple targets might enable the subjects practicing the task under the PV condition to develop a better proprioceptive representation of the task and, in the absence of vision, to avoid the large increase in aiming error noted in the first experiment. This would be especially true for a central target that is surrounded by other targets. This is the case because deviation from an optimal trajectory to reach this central target would result in the subjects necessarily approaching one or some of the remaining targets and would eventually permit them to recognize the nature of their error and initiate a correction.

METHOD

Subjects

Thirty-two healthy, self-declared right-handed subjects participated in this study. All subjects had normal or...
corrected-to-normal vision. Sixteen of these subjects were aged between 62 and 85 years old (mean of 71.8, SD = 5.62). They were recruited on a voluntary basis from a pool of regular participants in the social activities of an association of retired workers from the Montréal area. They were all living on their own and all reported having good health. Moreover, each of these subjects performed the DSST (Digit Symbol Substitution Test), an abridged version of the Weschler Adult Intelligence Test. The results of this test indicated that all subjects were representative of their age group (M = 48.6, SD = 6.55). The remaining 16 subjects were undergraduate students in the Department of Physical Education at the Université de Montréal. They were aged between 19 and 25 years old (mean of 22.3, SD = 3.07) and volunteered from introductory psychomotor behavior classes. None of the subjects had participated in Experiment 1; all were unfamiliar with the experimental task and conditions.

Subject’s Task and Apparatus

Apart from the differences noted below, the subject’s task and apparatus were similar to those used in Experiment 1. First, five different targets were used instead of one. The targets were defined by filtered (red) light of an optical fiber (diameter 0.5 mm; Belden, model 226001). The central target was located 30 cm from the starting base. The remaining four targets were located 7.5 cm above and below, and to the left and to the right of the central target. In order words, these targets marked the corners of an imaginary square having a side of 15 cm and centered on the central target. These targets were located in the central portion of a vertical plate (26 cm by 26 cm) which was slightly tilted toward the subject (38 degrees). This plate was covered by Teledeltos Recording Paper (Western Union Telegraph, model L-62s). This paper is isotropic resistive and, when fed by a current alternatively switched on its two axes, it permits the spatial accuracy of the movement to be measured to the nearest millimeter (via an eight-bit analog to digital converter) on both the X and Y axes of the target area (Bauer, Woods, & Held, 1969). The starting position was located close to the subject’s body, in line with his/her midline, while the central target was located 30 cm away in the sagittal plane.

Procedure

The procedures were similar to those used in the first experiment. However, subjects performed 120 trials in acquisition and 20 in transfer. In both experimental phases, each target was presented using a random schedule with the restrictions that: (a) each target was presented twice in each successive block of 10 trials, and (b) no repetitions of the same target occurred.

Because of the objectives of the present study, we contrasted the results obtained for the central target and those obtained for the corner targets. In acquisition, for the corner targets, the data were collapsed over blocks of 8 trials each, each block being composed of 2 trials for each of the 4 different targets. For the central target, there were 2 trials for each of the 12 blocks of acquisition. In transfer, the 4 trials performed for each corner target were collapsed into a single block of trials which was contrasted to a block of trials comprising the 4 trials performed toward the central target.

Finally, all these analyses were computed for the same dependent variables as in Experiment 1.

RESULTS

Acquisition

The data collected for each dependent variable during acquisition were submitted individually to a 2 age group (older vs younger) x 2 conditions of acquisition (PV vs P) x 2 types of targets (corners vs central) x 12 blocks of trials (1-10; 11-20, . . . 111-120) ANOVA with repeated measures on the last two factors.

Movement amplitude. — The mean results obtained for that dependent variable are illustrated in Figure 3. The ANOVA revealed two 2-way interactions. First, the breakdown of the first interaction into its simple effects shows that when only the central target is considered, the older subjects performed as accurately as their younger counterparts, F(1,44) = 1.45, p > .05. However, the younger subjects were more accurate than their older counterparts for the corner targets, F(1,44) = 16.7, p < .05. Second, although the central target always resulted in a lower RMSE (root mean square error) than the corner targets, the advantage found for the central target was larger in the P condition (7.26 mm vs 9.98 mm, respectively) than in the PV condition (4.31 mm vs 5.71 mm, respectively, F(1,28) = 4.9, p < .05. Finally, as illustrated in Figure 3, there was a small reduction of RMSE as a function of practice (from 8.7 mm to 6.06 mm), F(11,208) = 4.1, p < .05.

Movement direction. — The mean results obtained for that dependent variable are illustrated in Figure 4. The ANOVA only revealed that the younger subjects had a lower RMSE than their older counterparts, F(1,28) = 10.5, p < .05.

Movement time. — The statistical analysis did not reveal any significant difference in mean movement time. As can be seen in Figure 5 (top panels), the subjects had no difficulty in completing their movement within the prescribed bandwidth, beginning with the second block of trials. Con-
cerning the within-subject variability (see Figure 5, middle panels), the ANOVA revealed a significant interaction between the conditions of acquisition and the age groups, $F(1,28) = 4.68, p < .05$. This interaction indicates that the older subjects' MT was more variable in the PV than in the P condition (93 ms vs 68 ms), whereas the condition of acquisition had no effect on MT variability for the younger subjects (54 ms vs 61 ms, respectively). Figure 5 also illustrates the between-subject variability in MT. Although no statistical analysis could be computed on this dependent variable (only one score per cell), it reveals that the older subjects performed somewhat less homogeneously than the younger subjects.

**Acquisition vs Transfer**

The data collected for each dependent variable were submitted individually to a 2 age group (older vs younger) × 2 conditions of acquisition (PV vs P) × 2 types of targets (corners vs central) × 2 experimental phases (acquisition vs transfer), with repeated measures on the last two factors.

**Movement amplitude.** — First, and most important in the framework of the present study, the ANOVA revealed a significant interaction between the conditions of acquisition and the experimental phases, $F(1,28) = 16.1, p < .05$. As illustrated in Figure 3, this interaction indicates that the passage from acquisition to transfer resulted in an increase in RMSE for the subjects who had trained in the P condition, $F(1,28) = 4.4, p < .05$. However, for the subjects who trained in the PV condition, withdrawing vision in transfer resulted in a larger and significant increase of RMSE, $F(1,28) = 60.2, p < .05$. It is important to note that these effects were similar for both age groups and types of targets, $p > .05$. Finally, the central target yielded a lower RMSE than the corner targets (8.0 mm vs 10.9 mm), $F(1,28) = 35.5, p < .05$.

**Movement direction.** — As was the case for movement amplitude, the ANOVA revealed a marginally significant interaction between the conditions of acquisition and the experimental phases, $F(1,28) = 3.8, p = .06$. As illustrated in Figure 4, this interaction indicates that the passage from acquisition to transfer had no effect on RMSE for the subjects who had trained in the P condition, $F(1,28) = 2.3, p > .05$. Thus, KR withdrawal had no effect on direction accuracy. However, for the subjects who trained in the PV condition, withdrawing vision in transfer resulted in a large increase of RMSE, $F(1,28) = 18.6, p < .05$. Finally, the younger subjects had a lower RMSE than the older subjects (6.86 mm vs 10.0 mm), $F(1,28) = 7.0, p < .05$.

**Movement time.** — As illustrated in Figure 5 (upper panels), by the end of the acquisition phase, all four groups of subjects were good at completing their movement within the prescribed bandwidth and were able to perform equally well in transfer. However, although a similar level of within-subject MT variability was noted for the last block of acquisition of both the corner and central targets (58 ms vs 55 ms, respectively), a larger increase in variability was noted in transfer for the corner than for the central targets (140 ms vs 106 ms, respectively). This is supported by a significant experimental phases × types of targets interaction, $F(1,28) = 7.5$.

**DISCUSSION**

The first goal of this experiment was to determine whether, as in the first experiment, withdrawing the sight of
the hand in a transfer test would result in a large and similar increase in aiming error for older and younger subjects. Second, we wanted to determine if this increase in error would take place even when the subjects had the opportunity to explore a large area around a specific target.

Concerning the first goal, as in Experiment 1, withdrawing vision in transfer resulted in a large and similar increase in error for both the older and the younger subjects, who became less accurate than subjects who had trained in the P condition. This suggests that, given enough time to process it, the older subjects made a very similar use of the available sensory information (vision and proprioception) as younger subjects.

Concerning our second goal, we noted that the passage from acquisition to transfer had similar effects on aiming accuracy, regardless of whether we considered the central or the corner targets. This suggests that the large increase in error found in transfer for the subjects who practiced the PV condition was not only caused by the fact that the withdrawal of vision made them drift from a proprioceptively "known" area into an unexplored one. If such had been the case, a lower increase in error would have been found for the central than for the corner targets. Rather, these results suggest that withdrawing vision disrupted the reference of movement developed during practice. We will come back to the nature of this reference in the general discussion.

Finally, acquisition in the PV condition showed the older subjects to be as accurate as younger ones for the central target but not for the corner targets. This unexpected result is potentially important. When the same movement has to be repeated from one trial to the other, as in Experiment 1, it can be suggested that the older subjects planned their movement on trial \( n+1 \) at least partially in reaction to the outcome of trial \( n \). For example, they might better evaluate the significance of the error noted on a particular trial in relation to the programming of their next movement. Quickly, the movement becomes optimally planned and the subjects can possibly anticipate how and when to update it "en route" to the target (Keele, 1986). Given enough time to process optimally the sensory information available, older individuals perform as accurately as younger ones. Along this line of thought, when multiple targets are used, movement parameterization has to be modified from trial to trial. Moreover, it becomes more difficult to anticipate how to update an ongoing movement. Clearly, the younger subjects were very apt at making these adaptations, whereas it proved to be more problematic for older subjects. The older subjects' larger error might arise, first, from difficulty in parameterizing a different response from trial to trial. Second, the older individuals may have more problems than younger ones in detecting errors (Johnson et al., 1987; Jordan, 1978; Meeuwsen et al., 1993; Rosenhall & Rubin, 1975; Stelmach & Sirica, 1986) and issuing appropriate corrective motor commands when the target changes from one trial to the other. Now, the question that remains to be answered is: Why did the older subjects perform as well as younger ones for the central target?

Here, one must consider that the central target represented the algebraic as well as the geometric mean of the four corner targets. If, as suggested above, aging results in difficulty in adapting one's response from one trial to the other, it might be a good strategy to develop a motor response which is specific for a more probable movement or for a movement which best summarizes the class of movements to be performed. Thus, practice might lead the older subjects to develop a motor response which is optimally suited for the central target. It results in a movement which is as accurate as that noted when a single target is used (Experiment 1).

However, because the parameterization of this response must be adapted for the remaining targets, and because older individuals have difficulty (need a long time) to use sensory information to amend an ongoing movement, a decrease in accuracy is noted for the corner targets. On the other hand, younger subjects might be equally accurate regardless of the target because of their extensive and highly reliable use of sensory information to guide their movements toward the target. This interpretation is speculative and needs experimental confirmation.

**General Discussion**

The results of both experiments of the present study confirmed that practice of an aiming task in a situation in which one's hand is not visible does not result in a similar level of accuracy as that found under normal visual conditions (see Proteau, 1992 for a review). Therefore, the visual information available in the latter condition appears to be of major importance for optimal accuracy. Moreover, the withdrawal in a transfer test of that visual information does not simply result in individuals reverting to the use of proprioceptive information to control their movement. If such had been the case, the aiming accuracy in transfer would have been equivalent to that noted for the subjects who had trained in the proprioception-only condition. This was not the case, even for the central target used in Experiment 2; that is, for a situation of variable practice for which the subjects had had considerable practice around this target and, thus, had the opportunity to develop a proprioceptive calibration of the immediate area surrounding that central target. Rather, the subjects who had trained in a normal vision condition, regardless of their age group, became less accurate than the subjects who had trained in the proprioception-only condition.

For the older subjects, these results are different from those reported in our previous work (Chaput & Proteau, 1996; Proteau et al., 1994), in which we used shorter MT and showed that withdrawing vision resulted in the subjects performing as accurately as subjects who had trained in the P condition. However, the younger subjects behave very much alike in both sets of experiments. In line with the work of Teasdale et al. (1991) on postural control, the results of the present study suggest that the older subjects processed the visual information available for movement control during the acquisition phase of the experiment similarly to younger subjects. However, it appears that this is the case only when the time available is rather long. This indicates that aging brings a slowing in one or more processes responsible for the treatment of visual information rather than a different mode of processing as suggested in our previous work.
the present study concerned the amount of time for which visual information was available during the ongoing movement, it is likely that the different results were caused by the amount of time available for visual on-line control. Specifically, it might be that the target MT used in our previous work was not long enough to permit older subjects to process optimally the on-line visual information available. Although, to our knowledge, the visual feedback processing time of older subjects has never been directly evaluated, there are two lines of evidence supporting this view.

First, Goggin and Meeusen (1992) had older and younger subjects perform a spatially constrained aiming task (see Appendix). One combination of movement amplitude/target width used by these authors yielded a task somewhat comparable to that used in the present study [amplitude of 20 cm, target width of 1.0 cm: index of difficulty of 4.32 bits (Fitts, 1954)]. Under instructions to be as fast and as accurate as possible, the older subjects performed the task in a mean MT of 744 ms, of which 460 ms was spent in deceleration. Alternatively, younger subjects completed their movements in 456 ms, of which 290 ms were spent in deceleration. Similarly, Pratt et al. (1994) had younger and older subjects move a cursor shown on a computer screen from a starting position toward a target shown on the same screen. The subjects could move the cursor on the computer screen by rotating a handle held in their dominant hand. Reaching the center of the target required a 37-degree rotation of the handle and the target was 3.7 degrees wide, also yielding an index of difficulty of 4.32 bits (Fitts, 1954). On average, the older subjects needed approximately 620 ms to reach the target, whereas it took only 420 ms for the younger subjects. More importantly, the time spent following the first movement impulsion was of approximately 400 ms for the older subjects and remained constant across 200 trials of practice, whereas younger subjects spent less and less time in that movement phase, and only 200 ms after 100 practice trials. Because the time spent in deceleration (Goggin & Meeusen, 1992), or after the first impulsion (Pratt et al., 1994) is considered to be representative of an on-line control phase, these data suggest that older subjects needed between 400 and 460 ms to use the different sources of afferent information available (largely visual afferent information, Meyer et al., 1988) to correct their ongoing movement for it to be as accurate (or nearly as accurate, Pratt et al., 1994) as that of younger subjects. This suggests that, with relatively shorter MT as that used in our previous work, older subjects might not have sufficient time to process optimally the visual information available to correct their ongoing movement which, perhaps, led them to rely on a more open-loop mode of control.

A second line of support for this proposition comes from a study in which we showed (Abahnini, Proteau, & Temprado, 1996) that for young adults performing fast aiming movements, withdrawing vision of the last 15 cm (travelled in 80 ms) of a 41.5 cm aiming movement (MT of 300 ms) did not result in any decrease of directional accuracy. Considering that the actual estimates of visual feedback processing time are in the area of 100 ms for young adults (see Carlton, 1992), the results of Abahnini et al. (1996) support our interpretation that withdrawing visual information does not result in an increase in spatial error only when that information could not have been used for on-line control.

We suggest that the longer MTs used in the present study resulted in the older subjects becoming able to use more effectively the visual information available. The added time to process the available on-line information might have helped them to better evaluate the position of their hand in relation to that of the target as movement unfolded, to issue more accurate and/or more corrective commands, or a combination of both (future work will address each of these possibilities).

Regardless of the exact source of information, these results provide strong support for the proposition that, with the type of task used in the present study (high spatial accuracy demands), learning is specific to the sources of afferent information used during practice (Proteau, 1992). This specificity might occur because practice results in the development of an intermodal reference of the movement based on a tight integration of all sources of afferent information used for movement control (Chaput & Proteau, 1996; Proteau, 1992; Proteau et al., 1994). An alternative interpretation could be that, given enough time to process it, both older and younger subjects learned to use on-line visual information very effectively and progressively relied almost exclusively on it for movement control. For both these interpretations, withdrawing vision in transfer resulted in a large increase in error because the subjects, younger and older, were left without the main source of reference for movement control that had been developed in acquisition.

ACKNOWLEDGMENT

The research reported in this article was partially funded by grants awarded to the second author by the Natural Sciences and Engineering Research Council of Canada and by the Fonds F.C.A.R. from the Province of Québec.

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Received July 13, 1995
Accepted April 10, 1996

Appendix

Note

A spatially constrained task is a task in which the subjects are asked to hit a specific target on every single trial and for which MT is free to fluctuate for that goal to be reached. In contrast, the task used in our work is temporally constrained in that the subjects are asked to complete their movement within a specific MT bandwidth and spatial accuracy fluctuates for that goal to be reached.