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L'influence d'un modèle sur le chant des amusiques : Une solution au chant faux?

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L'influence d'un modèle sur le chant des amusiques :
Une solution au chant faux?

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a été évalué par un jury composé des personnes suivantes :

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Résumé

L'objectif était d'évaluer l'influence de la mémoire mélodique sur le chant des personnes souffrant d'amusie congénitale. Onze « amusiques » et 11 contrôles appariés ont chanté une chanson familière sur les paroles originales ainsi que sur la syllabe /la/. Les participants ont d'abord chanté la mélodie de mémoire et ensuite, ils ont imité la mélodie après et à l'unisson avec un modèle enregistré préalablement. Les résultats ont illustré que les amusiques ont amélioré leur performance en chantant par imitation (soit après, soit à l'unisson avec le modèle). Ceux qui présentaient une difficulté plus importante de la mémoire ont profité davantage du modèle, particulièrement lorsqu'ils chantaient sur la syllabe /la/. Ces résultats suggèrent qu'une mémoire faible pourrait être une cause des difficultés en chant. De plus, cette étude illustre que le chant par imitation semble être une méthode à privilégier pour améliorer la performance chantée.

Mots-clés : Amusie congénitale, chant, mémoire, modèle, imitation, erreurs de hauteur, performance.

Abstract

Our goal was to examine to what extent poor musical memory affects singing in congenital amusia. Eleven amusic individuals and 11 matched controls were asked to sing a familiar melody on the original lyrics and on the syllable /la/. Participants first sang the melody from memory, and then imitated the melody either after or in unison with a pre-recorded model. The results show that amusic individuals benefit from singing by imitation (after and along with a model). The amusics who exhibited severe memory impairment benefited most from the model, particularly when singing on the syllable /la/. These results point to music memory as a source of impairment leading to poor pitch singing, and to imitation as a useful aid for them.

Keywords: Congenital amusia, singing, memory, model, imitation, pitch errors, performance.

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En français :

BMEA : Batterie Montréalaise de l'Évaluation de l'Amusie

BPM : Battement par minute

En anglais :

IOI: Inter-Onset Interval

MBEA: Montreal Battery of Evaluation of Amusia

MIT: Melodic Intonation Therapy

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L'influence d'un modèle sur le chant des amusiques : Une solution au chant faux?

Apprécier la douceur d'un violon ou danser au rythme effréné d'un disque-jockey sont pour la majorité des gens, des expériences agréables et divertissantes. Or, pour les personnes qui souffrent d'amusie congénitale, les activités qui impliquent de la musique sont loin d'être plaisantes. En effet, ce déficit est caractérisé par l'incapacité à détecter consciemment des changements de hauteur, de reconnaître des chansons familières ou de percevoir des fausses notes au sein d'une mélodie (Ayotte, Peretz & Hyde, 2002; Peretz, 2001; Peretz, Champod & Hyde, 2003). Atteignant principalement le système perceptif, l'amusie congénitale n'est généralement pas détectée facilement. Cependant, les personnes qui en souffrent peuvent être contraintes à participer à des activités requérant un comportement musical. Dès lors, la distinction entre les personnes dites « amusiques » et la population générale deviendrait plus manifeste. Ce serait notamment le cas pour le chant (Dalla Bella, Giguère & Peretz, 2009). En effet, les amusiques sont reconnus pour être incapables de chanter avec justesse (Ayotte et al., 2002).

À ce jour, très peu d'études ont été menées sur le chant des amusiques. Bien que la littérature sur le chant des normaux ne soit pas plus abondante, elle permet tout de même d'accéder à une vision plus globale du phénomène et témoigne de la pertinence de son étude.

1.1. Le chant, un mode d'expression musical particulier

Ayant transcendé les cultures et sociétés (Mithen, 2006), le chant est une forme d'expression musicale universelle qui demeure très peu étudiée à ce jour (Berkowska & Dalla Bella, 2009). Par ailleurs, l'intérêt pour cette aptitude qui est largement distribuée au sein de la population (Dalla Bella, Giguère & Peretz, 2007) ne cesse de grandir chez les chercheurs.

Contrairement aux autres formes de production musicale, le chant apparaît spontanément et ce, très tôt dans le développement (Trehub & Trainor, 1999). En effet, dès les premiers mois de leur vie, les enfants tendent à imiter le chant maternel ainsi qu'à produire des vocalisations similaires à l'intonation de la parole (e.g. glissandi, voir Papousek, 1996). De plus, c'est âgé de 18 mois à peine qu'un enfant commence à produire des chansons (Ostwald, 1973). Bien qu'elles manquent de stabilité de la hauteur (Dowling & Harwood, 1986), ces chansons comportent certaines composantes importantes telles une rythmique répétitive ainsi qu'un contour mélodique (Ostwald, 1973). Ces composantes musicales produites par l'enfant permettent alors à un adulte de reconnaître la mélodie émise par le bambin (voir pour une revue Dowling, 1999, Ostwald, 1973 et Welch, 2006). D'autre part, la production d'une tonalité stable de même que d'un tempo régulier est acquise autour de la cinquième année de vie (Dowling & Harwood, 1986). À partir de cette période, l'enfant possède un important répertoire de chansons et son chant est qualitativement très similaire à celui qu'il produira à l'âge adulte.

Bien qu'il soit maîtrisé rapidement par la plupart des enfants, le chant demeure une activité extrêmement complexe, impliquant plusieurs réseaux cérébraux (Zarate & Zatorre, 2008). D'ailleurs, certaines applications cliniques ont résulté d'une meilleure connaissance de ces réseaux. La *Melodic Intonation Therapy (MIT)* (Albert, Sparks & Helm, 1973; Sparks, Helm & Albert, 1974; Helm-Estabrooks, Nicholas & Morgan, 1989; Helm-Estabrooks & Albert, 2004; Schlaug, Marchina & Norton, 2008) est un exemple de technique de réhabilitation qui utilise le chant pour améliorer la production de la parole. Elle fût développée suite à l'observation de cas d'aphasie sévère dans lesquels les patients chantaient des mots qu'ils ne pouvaient produire autrement. Plus précisément, cette technique consiste en un programme de réhabilitation qui utilise des expressions familières et des phrases. Le patient est invité à taper sur chaque syllabe pendant qu'il les fredonne (Racette, Bard & Peretz, 2006). Bien que cette technique de réhabilitation s'avère bénéfique pour certains patients (Norton et al., 2009), la littérature illustre qu'il y aurait autant de protocoles que de personnes qui l'utilisent. Un manque de bases théoriques à l'appui des protocoles pourrait être une explication de cette hétérogénéité. Or, malgré une littérature plus restreinte que celle des autres domaines des neurosciences de la musique, il existe tout de même des études pertinentes qui permettent de comprendre en quoi consiste le chant normal.

1.2. Chanter avec justesse : études sur le chant « normal »

Le chant produit par les enfants a suscité l'intérêt de plusieurs chercheurs, notamment de ceux provenant du champ de l'éducation musicale. Les études menées auprès d'enfants d'âge scolaire révèlent que la précision du chant est influencée par le contexte dans lequel il est produit. En effet, lors d'une tâche de production d'hauteur (« pitch-matching task »), les enfants imiteraient un modèle féminin avec plus de justesse qu'ils ne le font avec un modèle masculin (Green, 1990). Un contexte nécessitant un transfert d'octave (transposition) lorsque la voix du modèle est plus basse serait donc problématique pour les enfants.

D'autre part, plusieurs études se sont intéressées au lien entre la précision du chant et l'intégrité des habiletés de perception des enfants. Il semblerait qu'aucun accord ne serait présent dans la littérature (Berkowska & Dalla Bella, 2009). En effet, certains chercheurs évoquent qu'il y aurait une relation entre les habiletés de production et de perception (Demorest, 2001; Demorest & Clements, 2007; Phillips & Aitchison, 1997) alors que d'autres n'ont pas pu confirmer cette observation (Apfelstadt, 1984; Geringer, 1983; Robert & Davis, 1975). Enfin, plusieurs études suggèrent que la précision du chant augmenterait avec l'âge (Geringer, 1983; Goetze, 1985, Goetze, 1986; Gould, 1969; Green, 1990, Klemish, 1974; Yarbrough, Green, Benson & Bowers, 1991).

D'ailleurs, les études menées auprès des adultes illustrent que la majorité d'entre eux chante avec justesse (Dalla Bella & Berkowska, 2009; Dalla Bella et al., 2007; Pfordresher & Brown, 2007). Les chanteurs occasionnels disposeraient donc des habiletés nécessaires pour chanter avec justesse. Par exemple, ceux-ci présentent une mémoire précise pour la hauteur initiale ainsi que pour le tempo de chansons populaires (Halpern, 1989; Levitin, 1994; Levitin & Cook; 1996 ; Bergeson & Trehub, 2002). De plus, Dalla Bella et collègues (2007) ont illustré que les chanteurs occasionnels pouvaient produire une performance comparable à celle de chanteurs professionnels. Dans leur étude, les participants devaient chanter une mélodie hautement familière, soit la chanson *Gens du Pays* (Vigneault & Rochon, 1976), produite sur les paroles originales. Les analyses acoustiques ont révélé que les chanteurs occasionnels chantent typiquement avec le bon rythme. De plus, en chantant à un tempo plus lent (120 battements par minute (bpm)), ces chanteurs occasionnels améliorent considérablement leur performance en produisant un nombre d'erreurs de hauteur comparable à celui produit par les chanteurs professionnels. Or, le chant de deux participants est demeuré faux malgré le ralentissement de leur tempo. Ce chant qui est caractérisé comme étant faux, en quoi consiste-t-il?

1.3. Études sur le chant faux

Comment une performance est-elle catégorisée comme étant fausse? Dans la littérature, trois principaux critères semblent définir qu'une performance chantée est fausse (Berkowska & Dalla Bella, 2009). Certaines études évoquent des critères fixes où la production est catégorisée comme mauvaise s'il y a déviation de la cible par plus d'un demi-ton (e.g. Pfordresher & Brown, 2007). D'autres comparent les chanteurs à un groupe contrôle pour déterminer si la performance est normale ou déficitaire (e.g. Satoh, Takeda, & Kuzuhara, 2007; Schön et al., 2004). Enfin, certaines études catégorisent le chant en comparant chaque performance à la moyenne. Ainsi, une production qui s'éloignerait par plus de deux écarts-types de la moyenne, serait considérée comme déficitaire.

1.3.1. Chanter faux suite à une lésion cérébrale

Peu de recherches ont étudié le chant déficitaire survenant suite à une lésion cérébrale. Bien que certains cas soient relevés dans la littérature, la majorité d'entres eux demeurent plus anecdotiques que systématiques. Par ailleurs, des cas de chanteurs professionnels qui, suite à un dommage cérébral, présentaient un chant déficitaire sans désordre du langage ou de problème de perception musicale ont été relatés par Jossmann (1926, 1927, comme cité dans Benton, 1977) et par Botez et Wertheim (1959). Un exemple a été rapporté par Mann (1898, cité dans Benton, 1977) dans lequel un chanteur professionnel n'arrivait plus à chanter ou siffler des mélodies suite à une blessure au lobe frontal droit. Toutefois, malgré son déficit vocal, ce patient arrivait encore à reconnaître des mélodies familières et ne présentait aucun signe d'aphasie. Confavreux et collaborateurs (1992) ont rapporté le cas d'un patient qui chantait faux suite à une dégénération cérébrale focale des régions hémisphériques droites impliquant le gyrus antérieur temporal et l'insula. Ce patient présentait une perception de la hauteur relativement intacte en dépit de son chant déficitaire. Enfin, une étude menée par Schön et collaborateurs (2004) a permis d'illustrer qu'un chant faux peut survenir indépendamment d'un déficit de la perception de la hauteur. En effet, les auteurs ont rapporté le cas d'un chanteur ténor (IP) qui avait une lésion dans l'hémisphère droit se distribuant dans le gyrus inférieur frontal, le lobe temporal postérieur et le lobe pariétal inférieur. En présentant sélectivement un trouble de production d'intervalles musicaux, ce patient permet d'illustrer que l'amusie vocale pure peut survenir. Les désordres en chant pourraient donc apparaître sous une forme relativement pure. Or, il n'est pas rare que les difficultés en chant se présentent en l'absence de lésion cérébrale et que les personnes qui chantent faux soient décrites comme « n'ayant pas d'oreille musicale ». Le chant déficitaire serait-il davantage une conséquence d'un trouble du système perceptif ?

1.3.2. Chanter faux… Conséquence d'un trouble de la perception?

Chanter faux est fréquemment perçu comme étant la signature des personnes présentant des difficultés de perception musicale (Ayotte et al., 2002). En effet, les personnes qui reçoivent un diagnostic d'amusie congénitale, tel qu'évalué par *La Batterie Montréalaise de l'Évaluation de l'Amusie (BMEA)*, (Peretz et al., 2003) rapportent fréquemment l'anecdote selon laquelle les professeurs leur demandaient de faire semblant de chanter lors des cours de chorale. Récemment, Dalla Bella et collègues (2009) ont exploré, à l'aide d'analyses acoustiques, si le chant de ces personnes était réellement faux sur le plan objectif. Dans cette étude, 11 amusiques diagnostiqués à l'aide de la BMEA ont chanté de mémoire une chanson hautement familière soit, la chanson d'anniversaire produite sur l'air du refrain de "*Gens du Pays"* (par Gilles Vigneault). Les résultats provenant de ces analyses ont révélés que 9 des 11 amusiques présentaient un chant déficitaire. Le chant de ces amusiques comportait donc un nombre important d'erreurs de hauteur d'intervalle ainsi qu'un manque de stabilité de hauteur. Notamment, leur performance chantée était corrélée avec leur habileté de discrimination de la hauteur (Dalla Bella et al., 2009). Ce qui n'était pas le cas de deux amusiques de ce groupe qui présentaient un chant aussi juste que celui des contrôles. Bien que le chant faux apparaisse comme une conséquence d'un déficit du système perceptif, il pourrait aussi survenir suite à une faiblesse liée à une autre composante.

Une composante susceptible d'entraîner le chant déficitaire est la mémoire mélodique. En effet, certains résultats indiquent que les individus qui sont dépourvus d'habiletés musicales, des non-musiciens, ont des représentations mentales moins élaborées pour la musique, en particulier pour des situations nécessitant une classification explicite (Krumhansl & Shepard, 1979; Palmer & Krumhansl, 1990; Smitch, 1997). De plus, l'intégrité des représentations des hauteurs en mémoire affecterait la qualité du chant des amusiques (Dalla Bella et al., 2009). Il semble donc qu'une réduction de l'implication de la mémoire devrait diminuer le nombre d'erreurs dans le chant des amusiques.

1.4. Le chant choral, solution aux difficultés de production?

Des études menées auprès de participants disposant d'une bonne perception ont démontré que le chant produit avec un modèle serait plus précis que le chant produit seul. Par exemple, la précision du chant des enfants s'améliore beaucoup suite à l'écoute d'un modèle ayant un timbre et une octave comparable à leur propre voix (Green, 1994). Une étude de Wise et Sloboda (2008) a abordé la question auprès d'adultes se déclarant comme étant « tone-deaf » (TD), soit comme n'ayant pas d'habileté en chant, ainsi qu'auprès d'adultes normaux

(« not tone-deaf », NTD). En évaluant la perception de ces personnes avec la BMEA, il fût possible de voir qu'aucune d'entres-elles n'avaient un déficit comparable à celui des amusiques et ce, tant pour les personnes se déclarant comme « tone-deaf » que pour les personnes normales. Enfin, lorsqu'elles devaient chanter la chanson d'anniversaire « Bonne fête », tant les personnes se percevant « tone-deaf » (sans être « amusique » selon les critères de la BMEA) que les normales voyaient leur performance s'améliorer lorsqu'elles chantaient en même temps qu'un modèle. Selon les auteurs, la réduction de l'implication de la mémoire offerte par le modèle serait à l'origine de l'amélioration du chant des participants (Wise & Sloboda, 2008). Or, il semblerait que le chant chorale n'améliore pas toujours la performance. En effet, Pfordresher et Brown (2007) ont illustré que lorsque les participants chantaient en simultané avec une voix synthétique, leur performance était moins précise que lorsqu'ils chantaient sans accompagnement. Dans cette étude, les participants devaient reproduire des séquences de notes sous différentes conditions de rétroaction. Ainsi, la production s'effectuait soit sans manipulation de la rétroaction, en rétroaction « masquée » (ajout d'un bruit rose dans les écouteurs) ou en rétroaction « augmentée » (ajout d'une voix synthétique chantant la bonne séquence dans les écouteurs). Selon les auteurs, l'effet négatif d'un modèle sur la voix (ou rétroaction « augmentée »), témoigne d'un problème sensori-moteur comme principale cause du chant faux. En effet, l'incapacité à transmettre correctement les représentations auditives en représentations motrices pourrait être à l'origine des difficultés de production vocale.

Ainsi, il semblerait que dans une population dont la perception musicale est intacte, l'effet d'un modèle peut soit améliorer ou détériorer la performance. D'autres études devraient être menées afin de mieux comprendre comment un modèle peut influencer le chant.

1.5. L'influence d'un modèle sur le chant des amusiques

À ce jour, l'influence d'un modèle sur le chant des amusiques n'a pas encore été étudiée. Or, une fluctuation de la performance des amusiques dans un contexte où le niveau de rétroaction serait manipulé permettrait de mieux préciser les mécanismes régissant leur chant. D'abord, l'observation de la performance chantée des amusiques dans un tel contexte clarifierait la relation entre les mécanismes de perception et de production. En effet, si le chant faux est une conséquence directe d'un déficit du système perceptif, la production des amusiques devrait être peu influencée par un modèle. Par contre, dans le cas où le système perceptif ne régirait pas entièrement les mécanismes du chant, une amélioration de la performance pourrait être attendue.

D'autre part, l'analyse du chant produit avec un modèle permettrait aussi d'évaluer l'influence de l'intégrité de la mémoire sur la performance chantée. En effet, la présentation d'un modèle lors d'une tâche de chant pourrait réduire la demande mémorielle lors de la production d'une mélodie. Ainsi, en ramenant plus facilement la représentation de la mélodie en mémoire chez le chanteur peu expérimenté, celui-ci aurait la possibilité de se concentrer principalement sur sa production vocale.

Serait-il possible que chanter en simultané avec un modèle puisse diminuer l'implication de la mémoire pour ainsi permettre d'augmenter la justesse du chant ? Si un déficit au niveau de la mémoire mélodique entraîne le chant faux, est-ce que chanter avec un modèle serait une solution aux difficultés de production?

Accord des coauteurs

Article:

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Déclaration des coauteurs:

À titre de coauteur de l'article identifié ci-dessus, je suis d'accord pour que **Alexandra Tremblay-Champoux** inclus cet article dans **son mémoire de maîtrise** qui a pour titre:

L'influence d'un modèle sur le chant des amusiques : une solution au chant faux?

Simone Dalla Bella	Signature	Date
Jessica Phillips-Silver	Signature	Date
Marie-Andrée Lebrun	Signature	Date
Isabelle Peretz	Signature	Date

Article

Singing proficiency in congenital amusia: Imitation helps

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Running title: singing by imitation in congenital amusia

Keywords: congenital amusia, tone deafness, singing, memory, imitation, pitch, rhythm.

Abstract

Singing out of tune characterizes congenital amusia. Here, we examine whether an aid to memory improves their singing by studying vocal imitation in 11 amusic adults and 11 matched controls. Participants sang a highly familiar melody on the original lyrics and on the syllable /la/ in three conditions. First, they sang the melody from memory. Second, they sang it after hearing a model, and third, they sang in unison with the model. Results show that amusic individuals benefit from singing by imitation, whether singing after the model or in unison with the model. The amusics who were the most impaired in memory benefited most, particularly when singing on the syllable /la/. Nevertheless, singing remains poor on the pitch dimension; rhythm was intact and unaffected by imitation. These results point to memory as a major source of impairment in poor singing, and to imitation as a promising remediation aid for poor singers.

When an aria floats from the lips of an opera singer or when a child is humming his favorite song, the action engages multiple systems located in several cerebral areas to integrate what is perceived with what should be produced (e.g., Zarate & Zatorre, 2008) beyond basic processing in motor and sensory systems (Berkowska & Dalla Bella, 2009a). Moreover, singing is a universal form of musical expression that is mastered by the general adult population (e.g., Dalla Bella, Giguère & Peretz, 2007). Thus, the study of singing performance represents a unique opportunity to study music processing in its full complexity.

One of the best strategies to uncover the complexity of singing abilities is to study how it breakdowns as a consequence of a brain anomaly. This is the case of about 4% of the population who suffer from congenital amusia. Congenital amusia is characterized by poor singing (Ayotte, Peretz & Hyde, 2002). Most amusics sing out of tune as compared to controls, by both peers' judgments (Ayotte, Peretz & Hyde, 2002) and acoustical analyses (Dalla Bella, Giguère & Peretz, 2009). Their poor singing is typically associated with impoverished pitch perception.

However, there is growing evidence that perception and production abilities can be dissociated in singing. For example, poor pitch perception does not necessarily lead to poor pitch singing. In a study conducted by Loui and collaborators (Loui, Guenther, Mathys & Schlaug, 2008), amusic individuals (hereafter amusics) were able to reproduce pitch intervals in the correct direction while being unable to report whether the interval was going "up" or "down". Furthermore, Dalla Bella et al. (2009) identified two amusics who were able to sing a well-known melody as proficiently as controls, despite severe pitch perception deficits. Such dissociations point to the existence of separate neural pathways for pitch perception and production. According to Loui and collaborators (Loui, Alsop & Schlaug, 2009), the anomalous neural pathway concerns the right arcuate fasciculus which is reduced in congenital amusia.

The reverse dissociation can also be observed. Poor pitch singing can occur in individuals with apparently intact pitch perception. Pfordresher and Brown (2007) found that 10 to 15% of the population was inaccurate in imitating unfamiliar pitch patterns despite having normal pitch perception. The same proportion of poor singers with normal pitch discrimination has been found in the production of familiar melodies from memory (Dalla Bella et al., 2007; Dalla Bella & Berkowska, 2009). Altogether, the data suggest that vocal pitch production ability does not necessarily match pitch discrimination abilities.

As many functional components are required to sing in tune, such as pitch perception, sensorimotor integration, motor control, and memory systems (see Berkowska & Dalla Bella, 2009a, and Pfordresher & Brown, 2007, for reviews), a deficiency in any one of these components may lead to poor pitch singing. One system that has received little attention is memory. Yet poor memory for pitch is likely to affect singing, as a deficit in short-term memory for pitch material has been recently reported in congenital amusia (e.g., Tillmann, Schulz, & Foxton, 2009; Gosselin Jolicoeur & Peretz, 2009; Williamson et al., 2010). Similarly, Wise and Sloboda (2008) observed that self-reported "tone-deaf" individuals sang more poorly than self-reported "non tone-deaf" individuals, and this effect was greater for long than for short pitch sequences. Moreover, amusics exhibit poor levels of melody recognition and memorization in the long term (Ayotte et al., 2002). Reliance on degraded memory representations may explain at least in part why singing a well-known melody on a new speech segment (such as on /la/) is impossible for many amusics (Dalla Bella et al., 2009). Indeed, Dalla Bella and colleagues observed that amusics who scored lower on the memory test of the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod & Hyde, 2003) were those who failed to sing a well-known song on the syllable /la/. The authors argue that severe amusics may benefit from the strong association between melody and text in memory so that when the melody has to be sung with a new speech segment (the syllable /la/), singing breakdowns. The melody part would not be represented in sufficient detail to support singing. Note that normals sing more accurately on /la/ than with lyrics (Berkowska & Dalla Bella, 2009b). Thus, singing proficiency may depend on both short-term and long-term memory.

These observations are in line with recent neuroimaging evidence suggesting that long-term memory is tightly coupled with singing ability (Peretz et al., 2009). These authors found an activation of the right superior temporal sulcus when they compared cerebral responses to familiar versus unfamiliar music. The neuroimaging data further showed that familiar music was tightly coupled with action (singing), by involving the dorsal pathway (planum temporale, the supplementary motor area, and inferior frontal gyrus). Peretz and collaborators proposed a dual-stream process of familiar music processing whereby the ventral stream would serve for recognition and the dorsal stream, for singing.

In principle, providing a model to imitate should reduce the demands on the ventral pathway (memory) and improve the use of the dorsal pathway, thereby improving singing. Current behavioral evidence is mixed in this regard. While Wise and Sloboda (2008) and Dalla Bella and Berkowska (2009) reported a positive effect of both accompaniment and imitation on singing accuracy in occasional singers, Pfordresher and Brown (2007) did not observe any influence on the performance of poor singers when they sang in unison with the correct melody. However, materials and tasks were different in the three studies. Moreover, the aid of an accompaniment may not be related to memory. Singing with an accompaniment may promote sensorimotor synchronization, but not necessarily memory. Indeed, in some cases of brain-damaged patients, it is the synchronization with a model that improves vocal production, not imitation (Racette, Bard & Peretz, 2006).

The goal of the present study was to investigate the role of memory and synchronization on singing accuracy in both amusic and normal (matched) individuals. To this aim, we asked them to sing from memory a well-known song as well as to sing the same song after a model by imitation, and then again in unison with the same model. As memory load decreased across the three tasks, amusics' singing was expected to improve. In each condition, participants had to sing the song that is typically sung on birthdays in Quebec (i.e., the chorus of "*Gens du Pays"* by Gilles Vigneault), both with the associated lyrics and on the syllable /la/. We expected to observe more pitch errors when amusics sang from (long-term) memory than when they imitated the melody. Predictions were less clear regarding singing in unison with the model, since synchronization has been observed to influence performance both positively (Wise & Sloboda, 2008; Racette et al., 2006) and negatively (Pfordresher & Brown, 2007). Music memory was evaluated with the memory recognition test of the Montreal Battery of Evaluation of Amusia (MBEA; Peretz, Champod & Hyde, 2003).

Method

Participants. Eleven congenital amusics aged between 58 and 71 years (*M*=64.8 years) and 11 controls matched for age, education and musical background participated in the study. Six of the amusics had participated in the study of Dalla Bella et al. (2009). The distinction between amusic and control participants was based on performance on the MBEA; amusics had a composite score ranging between 51.1% and 71.1% (see Table 1), which was below the cut-off score for amusia (i.e., 77.6%; Peretz, Champod & Hyde, 2003). Results on the tests of the MBEA showed that all amusics were significantly impaired on the melodic dimension (i.e., in the scale, contour, and interval tests), while 8 of them performed on the rhythm or metric test as normals do.

(Table 1 about here)

An additional control group consisted of 10 university exchange students from France (hence referred to as the French group) without musical training who were unfamiliar with the song. All students did the Online Amusia Test (Peretz et al., 2008), to ensure that they were not amusic. Group characteristics and scores on the online amusia test are presented in Table 1.

Material and procedures. All participants performed a warm up in which they first imitated an exaggerated speech contour, to see if they could vary the pitch of their speaking voice. Second, they were asked to vary their vocal pitch up and down their full range. Before starting the experimental phase, the French subjects, who had never heard the target song, participated in a learning phase of the chorus of *Gens du Pays*. This phase consisted of listening to and repeating the song until all the lyrics could be produced. Pitch accuracy was not required in an attempt to make them more comparable to amusics who typically exhibit poor vocal pitch accuracy. All French participants were able to repeat the correct lyrics within one to three repetitions of the song.

(Figure 1 about here)

In the experimental phase, all participants were asked to sing the chorus of *Gens du Pays.* As illustrated in Figure 1, this chorus includes 32 notes (16 measures), and each note is associated with a different syllable. The pitch range lies within an interval of a major sixth (nine semitones), and the chorus has a stable tonal center in the key of F major. This song structure in which segment *a* is immediately repeated by the segment *a'* allowed us to evaluate pitch stability. Participants had to sing the chorus in three conditions and two contexts. First, they sang the chorus from memory (referred to as the 'spontaneous' condition). Next, they sang immediately after hearing a same-sex model ('after model' condition), and finally, in unison with the model ('unison' condition). The instruction was to sing as accurately as possible. In each condition (spontaneous, after model and unison), the participants sang with the original lyrics ('lyrics' context) first and then on the syllable /la/ ('la' context). Since all but the French participants were very familiar with the song, there was no practice trial.

There were two pre-recorded models, one female and one male, who sang at 120 beats per minute (bpm). This tempo is associated with best performance (Dalla Bella et al., 2007). The self-selected starting pitch of the female and male model was 223 and 196 Hz, respectively. As the same models were used in the 'after model' and 'unison' condition, the same key was used in both imitation tasks. Neither model was a professional singer to ensure a minimal amount of vibrato (as in Wise & Sloboda, 2008). Participants heard the model via Beyerdynamic DT770 Pro headphones in the 'after model' and 'unison' conditions. In the unison condition, participants heard the playback of their own voice in one ear and the model in the other ear in order to promote the use of self-monitoring. The participants' performance was recorded in a sound-attenuated booth with a Shure microphone, using Adobe Audition software.

Acoustical analyses of sung performance. When the sung performance included all 32 target tones, it was analyzed with the acoustic-based method developed by Dalla Bella et al. (2007, 2009). This method allowed us to automatically compute various measures of pitch and time accuracy for each recording. Analyses were carried out on the vowels (i.e., /a/ in "ta"). As vowels carry the maximum voicing and stable pitch information, these are the best targets for acoustical analysis (e.g., Murayama, Kashiwagi, Kashiwagi, & Mimura, 2004). Vowel onsets were identified using a semi-automatic procedure with EasyAlign (Goldman, 2007) as implemented in Praat software (Boersma & Weenink, 2007).

Using Praat, the onset of the vowel was computed as the *note onset time* and the median of the fundamental frequencies within vowels served to measure *pitch height.* To obtain the pitch and time variables of interest, note onset time and pitch height were analyzed with Matlab 7.1. software. The following measures of pitch and time accuracy were obtained. First, the *initial pitch,* which is the pitch of the first note of the song produced, was used to determine absolute pitch level. This measure was also used to assess the pitch distance from the model. The *pitch stability* was the difference between the pitches produced in the melody segment *a* and in the repetition *a'*. It was obtained by computing the average absolute difference (in semitones) between the 12 corresponding notes of the two song segments. The larger the mean difference, the more unstable was pitch in the performance. The number of *contour errors* was also calculated and represents the number of produced intervals that deviate in direction from their respective notated intervals. Pitch direction was counted as ascending or descending if the sung interval between two notes was higher or lower by more than one semitone. If pitch direction was different from the musical notation, it was counted as a contour error. Another measure, the *number of pitch interval errors,* indicated the number of produced intervals that deviated in magnitude from their respective notated intervals by more than one semitone. Pitch interval errors were coded irrespectively of pitch direction. That is, if a singer produced an ascending interval instead of a descending interval, this was not scored as a pitch interval error.

Finally, the *interval deviation* represented the size of the pitch deviations, by averaging the absolute difference in semitones between the produced and the notated intervals. Small deviations reflected high accuracy in relative pitch.

Variables on the time dimension were also computed. The *tempo* was the mean inter-onset interval (IOI) of the quarter note. The *number of time errors* indicated the number of duration deviations from the score. When a note was 25% longer or shorter than its predicted duration based on the preceding note, an error was scored. The first and last notes were not used to compute time errors. The *temporal variability* represented the coefficient of variation of the quarter note IOIs and was calculated by dividing the standard deviation of the IOI by the mean IOI.

Note that the acoustic-based analysis method could not be used to analyze an incomplete performance. As six amusics failed to produce all 32 notes of the chorus when asked to sing on the syllable /la/, we used the Melodyn 3.2 program in order to segment each note automatically and obtain the exact pitch (to the nearest cent) of the selected note. From these values, the contour and pitch interval errors were computed.

Results and comments

Song renditions with and without the associated lyrics were analyzed separately. In each context, we examined the mode of imitation first; we compared singing performance after hearing the model and in unison. Next, we assessed the role of memory by comparing singing accuracy in the two imitation conditions (after the model and in unison) to the singing from memory condition.

Singing with lyrics (*Imitation and unison*) Singing in unison did not improve performance over singing after the model and this was not due to a difficulty associated to synchronization with the model. Indeed, both amusics and controls were able to sing in time with the model. As an estimate of synchronization with the model, we measured the mean time lag between the model's onset and the produced note onset. Amusics started singing on average 320 ms (s.d.: 240 ms) after the model onset time, while controls started a little earlier, with 200 ms (sd: 108 ms). However, this group difference was not significant ($t(20) = 1.510$, *n.s.*).

(Figure 2 about here)

An ANOVA was run with two groups (amusics and controls) and two conditions (after model and unison) as a between-factor and within-subject factor, respectively, for each measure of accuracy[1]. As expected, amusics obtained lower scores than their matched controls for all pitch related variables across conditions (with $F(1,19) > 5.40$; $p < .05$). In neither group, there was any significant effect of the imitation condition on any variable, including on pitch interval errors, as illustrated in Figure 2 (all $F < 1$), despite the fact that singing in unison slowed down the tempo more than when singing after the model in both groups ($F(1, 19) = 24.59$, $p < .001$). Moreover, there was a positive correlation between the two imitation conditions on most variables in both amusics and controls (in amusics, $r = .90$, .81 and .70, $n = 11$, $p < 0.05$, for contour errors, pitch interval errors and time errors, respectively).

In order to assess the effect of a potential discrepancy between the starting pitch of the model and that of the singer, we measured the distance between the first note produced by model and the participant when singing after the model (because it was easier to isolate it in that condition). We then measured to what extent this distance in initial pitch predicted the number of errors produced in contour, pitch intervals and time. We found a positive correlation between the distance in initial pitch and the number of contour and of pitch interval errors produced in both controls and amusics (see Figure 3). In amusics, the larger the pitch distance the more contour errors, with $r = .80$, $n = 11$, $p = 0.001$, and pitch interval errors, $r = .70$, $n = 11$, $p = 0.001$, they made. Similarly, in controls, the corresponding correlations were $r = .66$, $n = 11$, $p = 0.05$ and $r = .76$, $n = 11$, $p = 0.05$, respectively. These results suggest that non-musicians in general are poor vocal pitch matchers. Only two amusics and five controls succeeded in matching vocally the initial pitch of the model by less than a semitone. Yet, these amusics made pitch errors. Thus, difficulties in transposition cannot fully account for their poor imitation.

(Figure 3 about here)

(*Contribution of long-term memory*) In order to assess the effect of long-term memory, we first assessed accuracy in singing without a model (from memory) and compared it to that in singing by imitation (by averaging performance across the after and unison conditions). When singing from memory, all amusics succeeded in producing the full set of 32 notes of the song with lyrics; the corresponding data are presented in Table 2. As previously observed (Dalla Bella et al., 2009), the production of amusics was characterized by poor pitch accuracy. Compared to controls, amusics' pitch production was less stable ($t(19) = 4.287$, $p < .001$), showed larger interval deviations ($t(19) = 5.773$, $p < .001$), and was characterized by more contour errors ($t(19) = 3.788$, $p < .005$) and pitch interval errors ($t(19) = 7.569$, $p < .001$). However, amusics' singing was comparable to normals on the temporal dimension in terms of tempo ($t(19) = -.744$, *n.s.*), temporal variability ($t(19) = .816$, *n.s.*), and number of time errors ($t(19) = 1.041$, *n.s*). Thus, in comparison to Dalla Bella et al. (2009) who found that a few amusic individuals had problems singing in time, the present results showed a performance that is comparable to controls on the temporal dimension. These observations are probably due to the slightly different sample of amusics and suggest that in most of them, a dissociation between melodic and rhythmic processing is present.

(Table 2 about here)

All but one amusic (ML) was severely impaired on the pitch dimension. ML sang in tune and within the range of controls on all variables (see arrow in Figures). This is a new case presenting a dissociation between (spared) pitch production and (impaired) pitch perception and is currently being studied in more detail.

In order to measure consistency in singing from memory over testing sessions, we compared the performance obtained by the six amusics who participated in both Dalla Bella et al.'s (2009) study and the present study. A sign test indicated that these amusics produced more pitch interval errors (M = 17.2) in the present than the prior study (M = 13.0, Z = -2.21, p = 0.03). The errors did not occur on the same notes in the melody on the two occasions (only 42.6% affected the same notes), suggesting that the memory representation of the song is unstable or imprecise.

As singing in unison and after the model was similar, we examined the global influence of a model (imitation) on singing accuracy. That is, we compared the mean score of imitation to the score obtained in singing from memory (without a model) on each acoustical variable. An ANOVA was run with the two groups (amusics and controls) and two conditions (memory and imitation) as between- and within-subject factor, respectively, for each type of error. As can be observed in Figure 4, imitation tends to increase pitch stability, to decrease contour errors and to reduce pitch interval deviations but the improvement only reached significance for the number of pitch interval errors in amusics ($F(1, 9) = 13.5$, $p < .01$) but not in controls ($F<1$); the interaction between Group and Condition was significant with $F(1, 19) = 5.71$, $p < .05$. Imitation was so effective in improving pitch accuracy that six amusics (JL, AS, EL, FA, GC and MB) succeeded in reaching normal performance in terms of pitch stability (see Table 3). In contrast, imitation did not improve performance in controls on any pitch-related variable (all $F < 1$). Moreover, no interaction between group and condition (memory, imitation) was observed for any of these variables.

(Figure 4 about here)

In order to assess the effect of pitch interval size on vocal performance, we further examined pitch interval deviations for each of the 31 intervals from the chorus (ranging from zero = repeated note, to nine semitones) when singing from memory and by imitation. The produced intervals were analyzed in an ANOVA with two conditions (spontaneous and imitation), five levels of interval size (2, 3, 4, 7, and 9 semitones) and two levels of deviation type (compression and expansion) as within-subjects factors, and group as a between-subjects factor. The analysis revealed a significant interaction between group, interval size and deviation type ($F(4, 80) = 3.56$, $p < .05$). Separate ANOVAs were then conducted in amusics and in controls. In amusics, there was no effect of interval size or of deviation type ($F < 1$), and no interaction between these two factors. In controls, a significant interaction between interval size and deviation type was found ($F(4, 40) = 6.36$, $p < .005$). When singing intervals of three semitones, controls exhibited a tendency to compress them.

On the time dimension, imitation slowed down the tempo in both amusics and controls ($F(1, 19) = 243.50$, $p < .001$) as compared to singing from memory. As singing at a slower tempo has been shown to reduce pitch and time errors (Dalla Bella et al., 2007), the reduction of pitch interval errors seen when singing by imitation could be due to this mediating speed factor. Whereas the model was useful in slowing down tempo, it did not reduce temporal variability ($F(1, 19) = 0.77$, *n.s.*) or time errors further ($F(1, 19) = 1.83$, *n.s.*; see Figure 5). This could be due to a floor effect.

(Figure 5 about here)

Singing on the syllable /la/ (*Imitation and unison*) Because amusics were highly variable in their ability to sing on /la/, they were separated into two groups based on their ability to complete the chorus of the song. Five amusics produced the full set of 32 notes when singing on /la/ from memory (AS, FA, GC, MB and ML) and six (BL, JL, EL, CB, IC and JG) failed to do so (see Table 4). Several individuals produced just a few notes and IC could not sing a single note. Therefore, IC will not be further considered in these analyses. Thus, about half of the amusics had a problem retrieving the melody from memory when requested to produce the song with the new speech segment /la/. A Pearson product-moment correlation coefficient was computed to assess the relationship between the memory test of the MBEA and the number of notes produced when singing from memory by amusics. There was a positive correlation between the two variables, with $r = .85$, $n = 11$, $p = 0.005$ (see Figure 6). This result supports the idea that music memory, as measured by the MBEA, predicts the ability to produce a well-known melody *without* the associated lyrics (Dalla Bella et al, 2009). We will refer to the two groups of amusics who can and cannot sing on /la/ as mildly versus severely memory-impaired, and these groups will be examined separately in the following analyses.

(Table 4 and Figure 6 about here)

In singing on /la/, there was a difference between imitation conditions. The severely memory-impaired amusics sang more notes in unison ($M = 31.2$) than after the model ($M = 24.1$) while the mildly memory-impaired produced the full set of 32 notes in both conditions. The interaction between group and condition was significant ($F(1, 9) = 11.21$, $p < .05$). Thus, synchronization with the model facilitated note production in the most memory-impaired cases.

Despite the fact that more notes were produced in unison than after the model, there was little difference in proficiency. The ANOVA with condition (after and unison) as within-subject factor and group (mildly memory-impaired, severely memory-impaired and control) as a between-subjects factor and percentage of errors as dependent variable, revealed no effect of conditions on any acoustical variables considered (all $F < 1$) nor interaction with this factor. In contrast, a significant effect of group was found on both the number of contour errors produced ($F(1, 18) = 14.93$, $p < .001$) and the number of pitch interval errors ($F(1, 18) = 21.32$, $p < .001$). Post hoc tests with Bonferroni correction showed that severely memory-impaired amusics produced more contour errors (47.9%) and pitch interval errors (63.6%) than mildly memory-impaired ones (16.2% and 34.5%, respectively) and controls (4.8% and 12.3%, $p < .001$).

(*Contribution of long-term memory*) The influence of imitation on singing accuracy was analyzed as previously. An ANOVA was run with condition (spontaneous and imitation) as a within-subject factor and group (severely memory-impaired amusics, mildly memory-impaired amusics and controls) as a between-subjects factor. The analysis showed that singing by imitation decreased the number of pitch interval errors ($F(1, 18) = 4.66$, $p < .05$). There was also a significant interaction between group and condition ($F(1, 18) = 3.91$, $p < .05$) indicating that severely memory-impaired amusics produced less pitch interval errors when singing with a model (63.6%) as compared to singing from memory (without a model: 80.8%) while the difference did not reach significance in the mildly-impaired (30.0% and 30.6 %, respectively). The number of contour errors did not differ between singing from memory and singing by imitation ($F(1, 18) = 1.54$, *n.s.*).

Effect of familiarity The chorus of *Gens du pays* is an over-learned song in Quebec. Thus, familiarity may have contributed to the limited effect of a model on singing proficiency in controls. In contrast, for the French students this was a novel song. To evaluate the effect of long-term exposure to the song on singing proficiency, performance of the French group was compared to the control group (see Table 2). When singing with lyrics, the French participants produced larger interval deviations ($t(18) = -1.985$, $p < .05$) and more contour errors than the

Quebec controls matched to the amusics (*t*(18) = -2.329, *p* < .05). Pitch stability and number of pitch interval errors did not differ between the two groups (*t*(18) = -1.097 and -1.450, respectively). On the time dimension, the French group sang at a slower tempo than controls (*t*(18) = -4.120, *p* < .005), which might have contributed to the limited number of pitch interval errors that they produced (Dalla Bella et al., 2007). Finally, they did not differ from controls in terms of temporal variability (*t*(18) = 1.375, *n.s.*) or time errors (*t*(18) = 0.752, *n.s.*).

All French subjects succeeded in producing the complete rendition of the song on the syllable /la/ and were as accurate as controls in terms of contour and pitch interval errors (*t*(18) = -0.600 and –1.273, *n.s.,* respectively). Finally, there was no evidence that singing in unison was of any aid. All comparisons between the unison and after model condition were not significant. Furthermore, there was no difference between singing from memory as compared to singing by imitation on the number of contour errors (*F*(1, 19) = 2.86, *n.s.*) and pitch interval errors (*F* < 1). Overall, these results suggest that imitation is of limited aid under normal conditions.

Conclusion

Singing by imitation decreased the number of pitch interval errors as compared to singing from memory in amusics. Moreover, the model helped half the amusics to sing the melody on /la/. In particular, we observed that singing on the syllable /la/ was very laborious for half of the amusics, who were also the most severely impaired in the recognition of novel melodies from memory. This result supports the idea that poor memory contributes to poor singing.

However, singing by imitation also slows down tempo. As shown previously, singing at a slower tempo reduces pitch and time errors in occasional singers (Dalla Bella et al., 2007). Thus, the observation of an improvement in pitch accuracy when singing by imitation as compared to singing from memory could be due to this mediating speed factor, not only memory. What is very likely is that a degraded memory representation of a song exacerbates poor singing. Providing an aid in the form of a model to imitate or to sing along is effective but insufficient, as all amusics remained poor singers in such conditions. This is consistent with the prior observation that vocal pitch-matching abilities are impaired in congenital amusia across different pitch heights and feedback conditions (Hutchins et al., 2010).

In contrast, the aid of a singing model could not be demonstrated in normal controls. We found little influence of the model on the performance of French subjects who learned the song just before testing. Although the learning episode reduced the singing tempo of the French group as compared to the Quebec singers, imitation did not further reduce the size of pitch deviations or the number of contour errors. These results suggest that singing by imitation is of limited aid in general, but effective in poor singers with poor memory. However, the role of imitation in singing is confounded here with the learning method. The French participants learned the song by imitation just before testing. A different pattern might emerge if the same group were tested in a separate session. Indeed, the Quebec singers did show some slight benefit from listening to someone else as compared to singing alone from memory.

It should be noted that all participants were tested here in the same fixed order, with singing from memory followed by singing after a model and then in unison with the same model. Although singing alone (from memory) had to be performed first in order to isolate the effect of memory from the potential influence of a model, singing after or in unison with the model can be counterbalanced within and across subjects. With repeated practice in the two conditions with a model, amusics, particularly the most memory- impaired ones, might have improved their singing proficiency in chorus singing. Testing this possibility should be the goal of future testing, preferably in using an unfamiliar song to avoid ceiling effects in control participants. An adaptive procedure would be a well-suited design, as shown previously in normal students and aphasic patients (Racette & Peretz, 2007; Racette et al., 2006).

In sum, imitation can support singing in severe cases of poor singing. It is worth mentioning that the present situation is advantageous by being more ecological than prior studies in several aspects. For example, Pfordresher and Brown (2007) used a synthesized voice as a model and participants listened to their own singing at a reduced volume as compared to the synthesized voice. This setting may explain why singing with a model in this prior study was not effective, at least for the poor singers. In the present study, the model was a pre-recorded natural voice, leaving the possibility for the singers to monitor their own voice as distinctly as the model. Thus, new rehabilitation strategies may exploit similar settings and target both speed and memory in poor singers in order to moderate the severity of their singing disorder. However, in futures studies, the long-term benefits of imitation should be assessed, especially in amusics who suffer from severe memory problems. By testing amusics after a delay, it could be possible to evaluate if singing by imitation can be a long-term rehabilitation strategy, not only an immediate one.

Footnotes

[1]Preliminary analyses showed that there was no effect of gender, nor any interaction with this factor.

Table 1. *Characteristics of congenital amusics and controls, percentages of correct responses on the MBEA and on the Online test of amusia.*

	BL	JL	AS*	EL*	FA*	GC*	IC*	MB*	CB	JG	ML	Controls (SD)	French group (SD)
Gender	M	M	F	F	F	F	M	F	M	M	F	7F 4M	6 F 4M
Age (years)	63	71	67	58	68	62	65	66	67	60	68	64.8 (5)	22.8 (3.7)
Education	14	15	14	19	15	20	19	21	19	19	15	17.1 (3)	19.8 (4.7)
Musical Background:	1	1	2	3	2	1	1	4	1	1	0	2.5 (2)	0
MBEA:													
Scale	63.3[a]	66.7[a]	63.3[a]	53.3[a]	66.7[a]	56.7[a]	50[a]	46.7[a]	58.1[a]	53.3[a]	56.7[a]	92 (6)	n/a
Contour	60[a]	73.3[a]	63.3[a]	53.3[a]	70[a]	56.5[a]	50[a]	46.7[a]	67.6[a]	56.7[a]	63.3[a]	89 (8)	n/a
Interval	53.3[a]	56.7[a]	60[a]	53.3[a]	70[a]	73.3	50[a]	73.3	41.9[a]	66.7[a]	50[a]	87 (8)	n/a
Rhythm	76.7	83.3	76.6	63.3[a]	66.7[a]	96.7	50[a]	93.3	76.7	80	53.3[a]	88 (8)	n/a
Metric	50[a]	53.3[a]	60[a]	73.3	66.7[a]	70[a]	56.5[a]	70[a]	43.3[a]	56.7[a]	66.7[a]	87 (8)	n/a
Memory	56.7[a]	70[a]	73.3[a]	66.7[a]	76.7[a]	73.3[a]	50[a]	76.6[a]	63.3[a]	66.7[a]	70[a]	92 (6)	n/a
Composite score	60[a]	67.2[a]	66.1[a]	60.6[a]	69.4[a]	71.1[a]	51.1[a]	67.8[a]	58.5[a]	63.3[a]	60[a]	89 (3)	n/a
Online test amusia:	49	76	60	51	52	69	38	83	59	61	62	89.0 (4.9)	91.3 (4.4)

n/a = not available; * indicates amusics who participated in Dalla Bella et al.'s (2009) study; [a] below cut-off score as indicated in Peretz *et al.*, 2003

Table 2.

Mean values for pitch and time variables obtained when singing from memory with lyrics. The maximum value is 31 for contour and pitch intervals.

Variables	Amusics *M* (range)	Controls *M* (range)	French group *M* (range)
		Pitch dimension	
Initial pitch (Hz)			
Males	**121.8 (86.8 - 175.0)**	**140.4 (131.7 - 162.0)**	**146.45 (95.4 - 187.9)**
Females	**224.1 (217.0 - 234.6)**	**249.2 (220.0 - 331.6)**	**207.27 (131.7 - 243.1)**
Pitch stability (semit.)	**2.0 (0.4 – 3.0)**	**0.6 (0.3 – 1.0)**	**0.83 (0.2 - 2.3)**
N. of contour errors	**9.6 (0.0 – 23.0)**	**1.6 (0.0 – 3.0)**	**6.0 (0.0 – 9.0)**
N. of pitch interval errors	**18.2 (2.0 – 25.0)**	**6.0 (0.0 – 8.0)**	**10.0 (1.0 – 17.0)**
Interval deviation (semit.)	**1.8 (0.7 - 3.9)**	**0.7 (0.3 - 0.8)**	**1.4 (0.3 – 2.0)**
		Time dimension	
Tempo (Mean IOI, ms)	**300.8 (193.0 – 353.0)**	**313.4 (230.0 - 367.0)**	**420.0 (257.1 – 542.0)**
N. of time errors	**6.3 (2.0 – 12.0)**	**4.8 (1.0 - 7 .0)**	**4.0 (0.0 – 7.0)**
Temporal variability	**0.3 (0.2 - 0.4)**	**0.2 (0.1 - 0.5)**	**0.2 (0.1 - 0.2)**

Table 3. Mean values for pitch variables obtained by the six amusics (JL, AS, EL, FA, GC, MB) who reached normal performance on pitch stability when singing by imitation.

Variables	**Amusics** **_M_ (range)**		**Controls** **_M_ (range)**	
	Spontaneous	**Imitation**	**Spontaneous**	**Imitation**
Pitch dimension				
Pitch stability (semit.)	**1.5 (0.6 - 2.3)**	**0.9 (0.2 - 1.6)**	**0.6 (0.3- 0.9)**	**0.7 (0.3 - 1.9)**
N. of contour errors	**6.5 (2 - 17)**	**4.4 (0 - 9.5)**	**1.6 (0 - 3)**	**2.4 (0 - 6)**
N. of pitch interval errors	**17.3 (12 - 25)**	**12.5 (1 - 24)**	**6.0 (0 - 8)**	**5.0 (0 - 12)**
Interval deviation (semit.)	**1.6 (1.0 - 2.7)**	**1.2 (0.4 - 2.1)**	**0.7 (0.3 - 0.8)**	**0.7 (0.3 - 1.1)**

Table 4. Number of notes produced by amusics when singing on /la/.

Number of notes produced	BL	JL	AS	EL	FA	GC	IC	MB	CB	JG	ML	Controls
When singing spontaneously:	11	12	32	18	32	32	0	32	26	17	32	32
When singing after a model:	16	31	32	22	32	32	0	32	25	21	32	32
When singing in unison with a model:	28	32	32	32	32	32	27	32	32	32	32	32

Figure 1

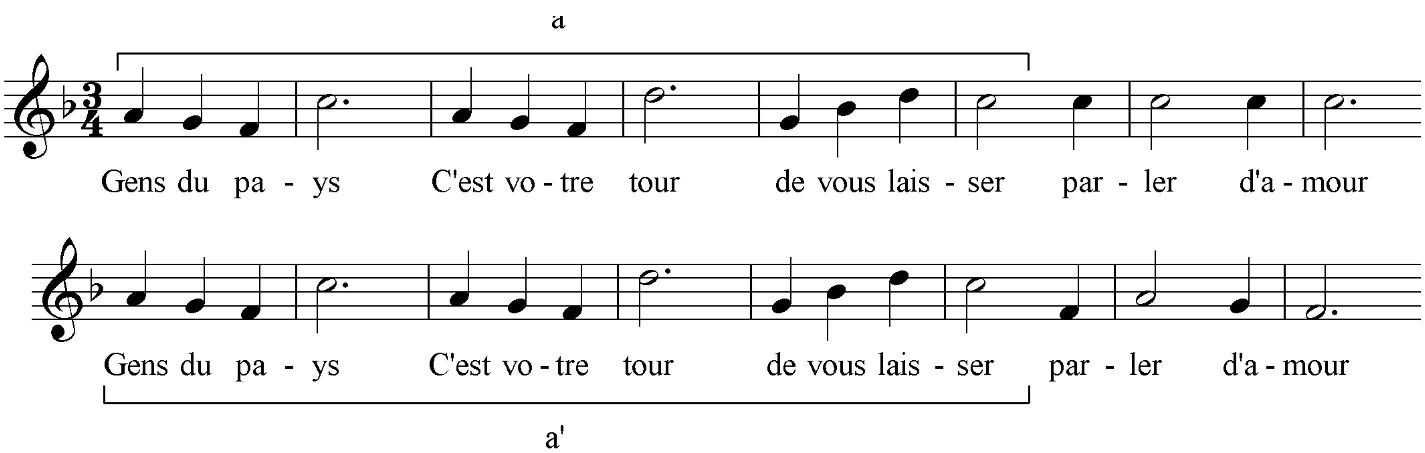

a
Gens du pa - ys C'est vo - tre tour de vous lais - ser par - ler d'a - mour
Gens du pa - ys C'est vo - tre tour de vous lais - ser par - ler d'a - mour
a'

Figure 2

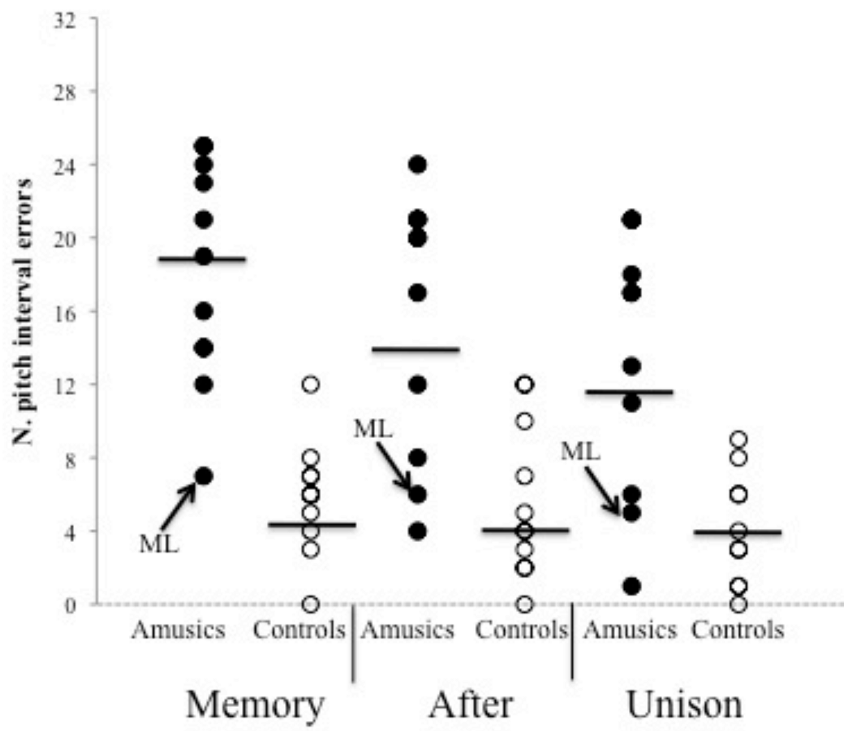

N. pitch interval errors
32
28
24
20
16
12
8
4
0
ML
ML
ML
Amusics
Controls
Amusics
Controls
Amusics
Controls
Memory
After
Unison

Figure 3

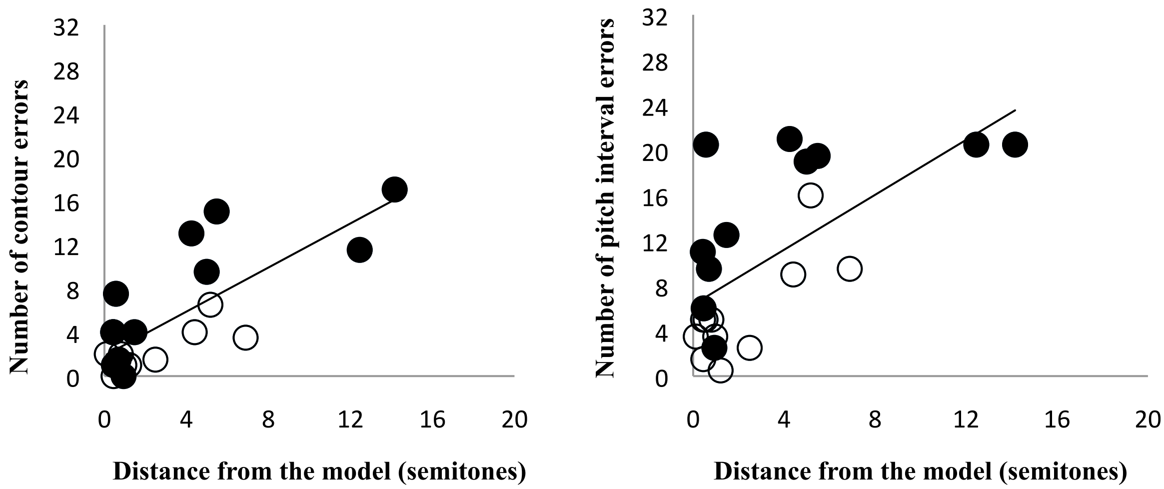

Number of contour errors
0
4
8
12
16
20
24
28
32
0
4
8
12
16
20
Distance from the model (semitones)
Number of pitch interval errors
0
4
8
12
16
20
24
28
32
0
4
8
12
16
20
Distance from the model (semitones)

Figure 4

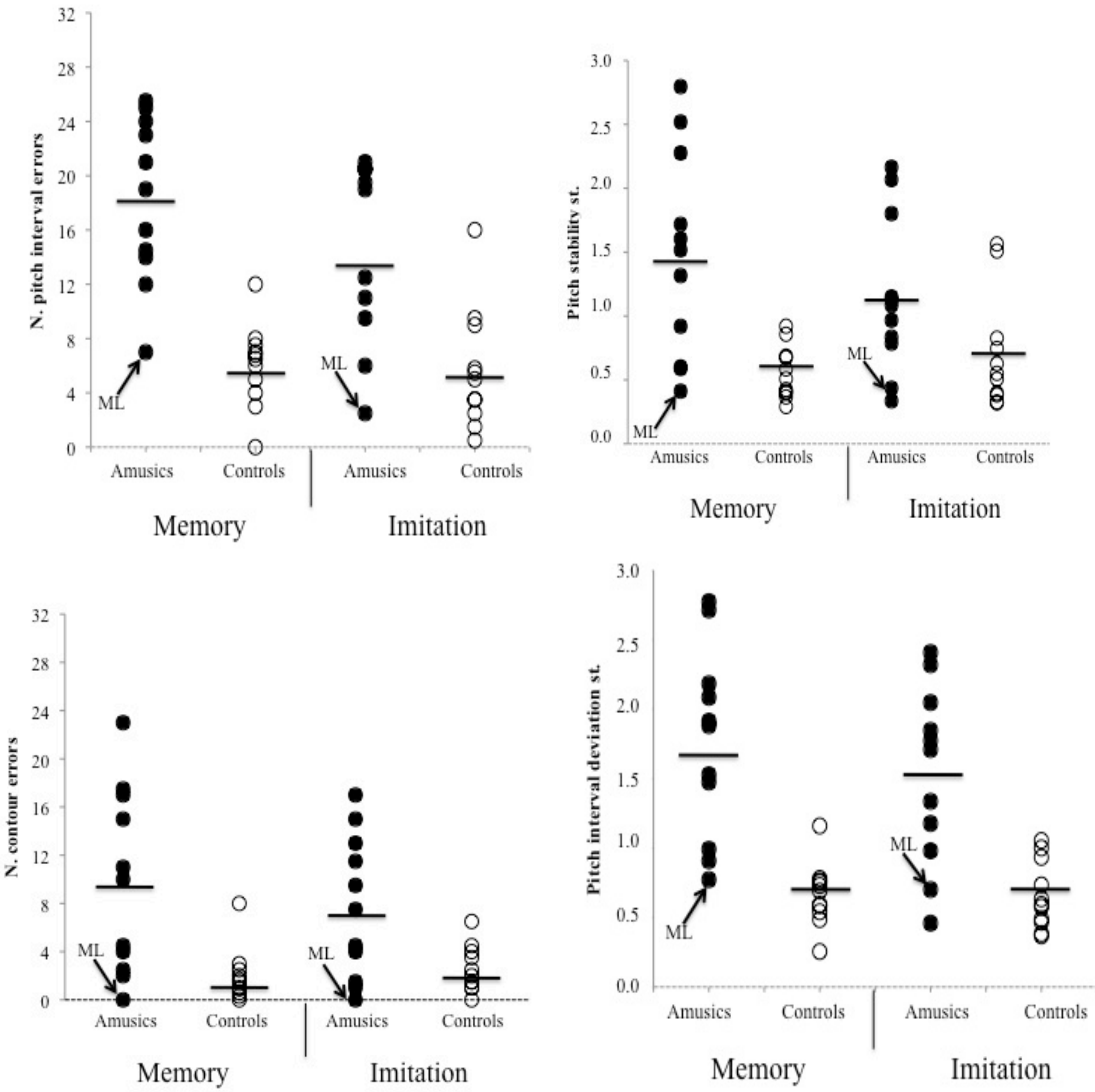

N. pitch interval errors
32
28
24
20
16
12
8
4
0
ML
Amusics
Controls
Amusics
Controls
Memory
Imitation
Pitch stability st.
3.0
2.5
2.0
1.5
1.0
0.5
0.0
N. contour errors
Pitch interval deviation st.

Figure 5

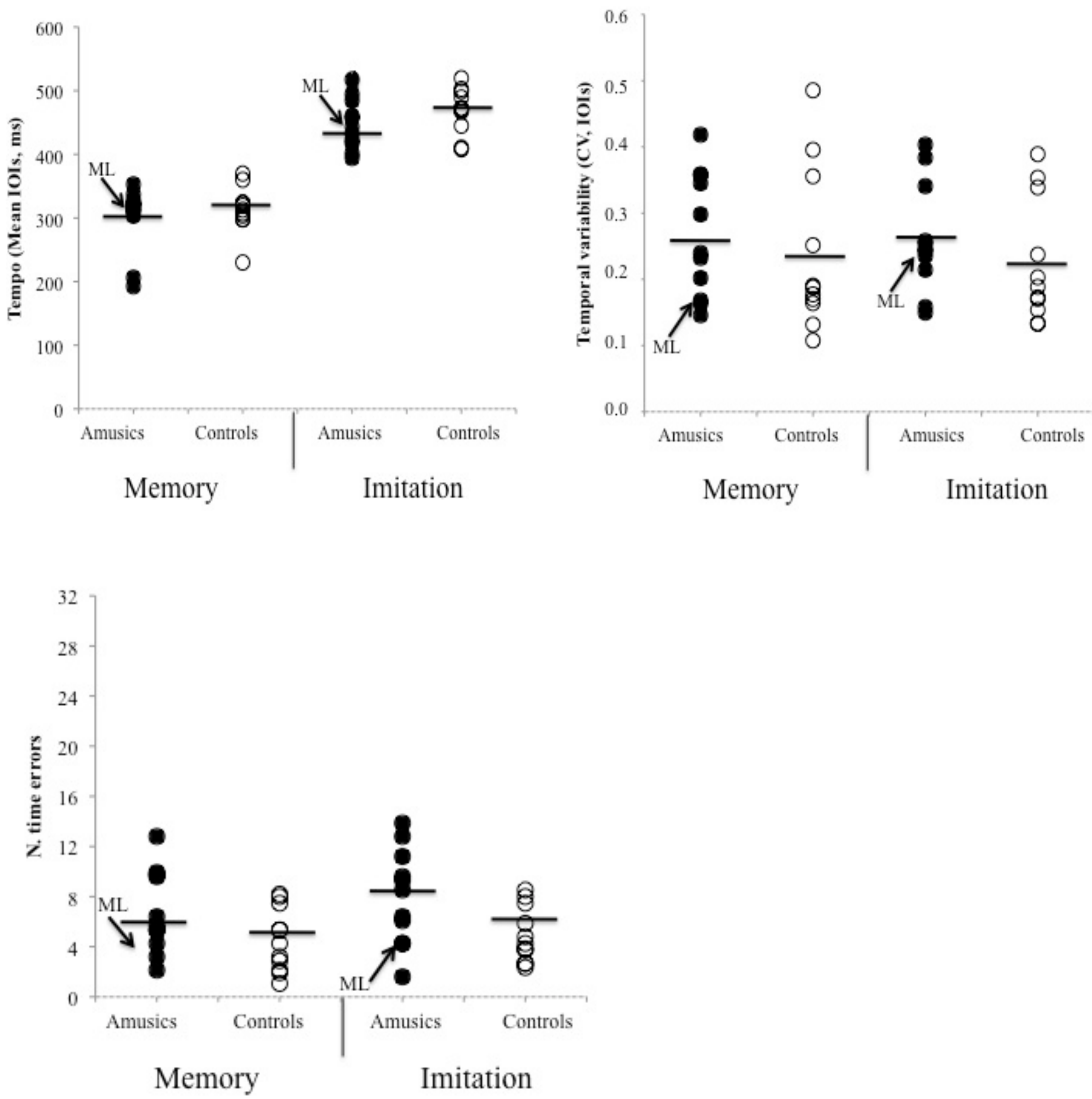
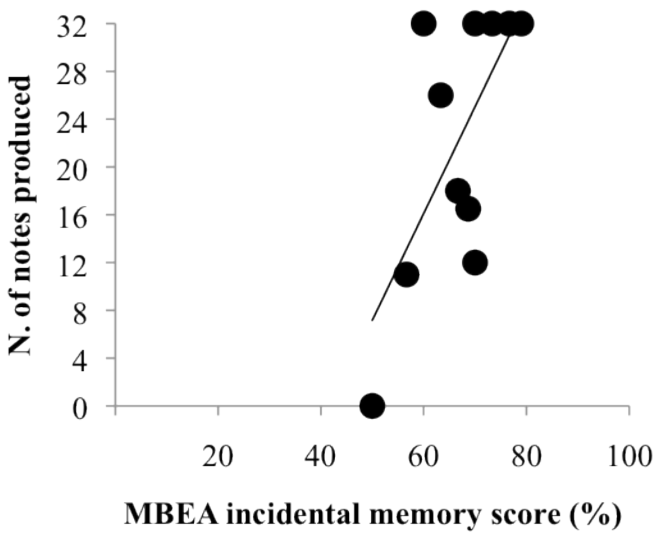

Tempo (Mean IOIs, ms)
600
500
400
300
200
100
0
ML
ML
Amusics
Controls
Amusics
Controls
Memory
Imitation
Temporal variability (CV, IOIs)
0.6
0.5
0.4
0.3
0.2
0.1
0.0
ML
ML
Amusics
Controls
Amusics
Controls
Memory
Imitation
N. time errors
32
28
24
20
16
12
8
4
0
ML
ML
Amusics
Controls
Amusics
Controls
Memory
Imitation

Figure 6


N. of notes produced
0
4
8
12
16
20
24
28
32
20
40
60
80
100
MBEA incidental memory score (%)

Discussion générale

L'objectif général de ce mémoire était d'étudier la production vocale des personnes souffrant d'amusie congénitale. Plus spécifiquement, l'étude présentée dans l'article avait pour but de mieux comprendre le rôle de la mémoire dans le déficit de production vocale ainsi que d'évaluer l'effet d'un modèle sur le chant. Les résultats ont illustré qu'un déficit de production vocale pouvait être en partie la conséquence d'une mémoire mélodique pauvre. En effet, la performance chantée des amusiques était améliorée lorsqu'ils chantaient soit après ou à l'unisson avec un modèle, suggérant ainsi que leur chant faux ne découlerait pas uniquement de leur déficit de perception. De plus, leur habileté à compléter la chanson sur de nouvelles syllabes était fortement corrélée à leur score obtenu au sous-test de mémoire mélodique de la BMEA. Enfin, les amusiques qui présentaient une mémoire mélodique plus pauvre étaient ceux qui bénéficiaient le plus de l'aide du modèle. En somme, ces résultats suggèrent qu'un appauvrissement de la mémoire mélodique semble être une cause importante, mais non suffisante, pour expliquer les déficits de production observés chez la majorité des amusiques.

Dans une perspective future, ces résultats devraient être approfondis au plan structurel et fonctionnel. En effet, l'utilisation d'imagerie par résonnance magnétique (IRMf) permettrait de spécifier les conditions cérébrales conduisant au déficit de production vocale. À ce jour, encore très peu d'études ont investigué les corrélats neuronaux impliqués dans le chant des amusiques. Les quelques données existantes sur les corrélats neuronaux de l'amusie congénitale suggèrent la présence d'une déconnexion fonctionnelle entre le gyrus frontal inférieur et le cortex auditif (Hyde, Zatorre, & Peretz, 2010). Puisqu'au moins trois faisceaux de fibres relient ces deux régions cérébrales (Friederici, 2009), une hypothèse à explorer serait que l'amusie résulterait d'une réduction de la voie ventrale surtout et de la voie dorsale dans une moindre mesure. Une telle observation permettrait de comprendre pourquoi certains amusiques présentent plus de difficultés à percevoir la musique (voie ventrale) qu'à chanter (voie dorsale).

D'autre part, puisque le profil inverse existe aussi (des individus qui perçoivent bien la musique et qui éprouvent des difficultés à chanter (Pfordesher & Brown, 2007)), il semble que la poursuite des recherches sur le chant faux devrait s'effectuer dans un groupe composé à la fois de gens souffrant d'amusie congénitale et de personnes présentant un déficit de production tout en disposant d'une perception normale.

En guise de conclusion, cette étude a permis de spécifier les mécanismes impliqués dans le déficit de production affligeant la majorité des amusiques. Une définition plus complète du fonctionnement de la production dans l'amusie congénitale permettra de mieux comprendre l'organisation du cerveau au niveau des fonctions musicales. Dans une perspective de réhabilitation, ces informations seront nécessaires afin de guider le développement de thérapies potentielles pour l'amusie congénitale

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