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École doctorale 139 : Connaissance, langage, modélisation
Laboratoire Ethologie Cognition Développement (LECD)

Membre de l'université Paris Lumières

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Influence de la musique, préférences musicales et production sonore et rythmique chez les perruches calopsittes et les corbeaux à gros becs

Thèse présentée et soutenue publiquement le 27/11/2019
en vue de l'obtention du doctorat de Ethologie et cognition comparées de l'Université Paris Nanterre
sous la direction de Mme Dalila Bovet (Université Paris Nanterre)

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Influence de la musique, préférences musicales et production sonore et rythmique chez les perruches calopsittes et les corbeaux à gros becs

Influence de la musique, préférences musicales et production sonore et rythmique chez les perruches calopsittes et les corbeaux à gros becs

De nombreuses hypothèses ont tenté d'expliquer l'émergence de la musique au sein de l'humanité. Des études ont montré que les animaux non-humains, et notamment les oiseaux, pouvaient aussi y être sensibles. Nous nous sommes donc intéressés à la sensibilité musicale chez deux espèces d'oiseaux : les calopsittes élégantes et les corbeaux à gros becs. Nous avons étudié l'influence de la musique en leur diffusant différents types de musique : la musique, surtout consonnante, induit des différences comportementales et des interactions positives chez les calopsittes mais pas chez les corbeaux. Une étude comparative effectuée chez les enfants montre des résultats similaires à ceux des calopsittes. Nous avons aussi étudié les préférences musicales des oiseaux, pour les corbeaux en évaluant leur distance par rapport au haut-parleur diffusant la musique et pour les calopsittes en leur proposant un écran tactile leur permettant de déclencher différents types de musique : certaines calopsittes ont montré des préférences individuelles, mais pas les corbeaux. Enfin nous avons étudié leurs productions sonores : les calopsittes ont produit différents sons avec des objets mis à leur disposition, l'un d'entre eux utilisant même un outil dans ce but. Les tambourinages spontanés avec le bec montrent une certaine régularité chez les deux espèces. Ce travail a permis de montrer que les calopsittes remplissaient plusieurs critères caractérisant la musique. Il a aussi permis de discuter plusieurs hypothèses portant sur l'évolution de la musique. De plus, il peut donner des pistes en matière de bien-être animal.

musique ; musicalité ; oiseaux ; cacatuidae ; perroquets ; corbeaux ; influence de la musique ; préférences musicales ; production sonore ; rythme

Influence of music, musical preferences and rhythm and sound production in cockatiels and jungle crows

Many hypotheses tried to explain the appearance of music in mankind. Some studies showed that non-human animals, and specifically birds, would be sensitive to music too. Thereby, we studied musical sensitivity in two species of birds: cockatiels and jungle crows. We studied the influence of music by broadcasting them several types of music: music induces behavioural differences and positive interactions in cockatiels, particularly for consonant music, but not in jungle crows. A comparative study with children also shows positive effects of music (particularly consonant). We also studied birds' musical preferences, for the crows by recording their distance to the loudspeaker broadcasting music and for the cockatiels with a touch screen allowing them to trigger several types of music: some cockatiels displayed individual preferences, but not the crows. Finally we studied their sound productions by providing the cockatiels with several supports producing sounds and by analyzing beak drumming sequences in those two species: the cockatiels produced several sounds with the provided objects, one of them even using a tool in that purpose. The drumming sequences show some regularity in both species. This work showed that the cockatiels fulfill several criteria that characterize music. It also allowed us to discuss several hypotheses regarding the evolution of music. Furthermore, it could inspire some ideas concerning animal welfare.

music ; musicality ; birds ; cacatuidae ; parrots ; crows ; influence of music ; musical preferences ; sound production ; rhythm

Cette thèse a été préparée au sein du Laboratoire Ethologie Cognition Développement de l'Université Paris Nanterre.

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Cette thèse est née d'une grande passion pour les oiseaux qui m'accompagne depuis près de vingt ans. Je tiens donc à remercier particulièrement tous ceux qui, de près ou de loin, m'ont soutenue dans cette grande aventure et l'ont rendue possible.

Un grand merci à ma directrice de thèse Dalila Bovet pour m'avoir fait confiance lorsque j'ai évoqué mon envie de travailler sur la musique, et pour avoir su me guider tout au long de ces années sans me retirer ma liberté. Merci aussi d'avoir toujours compris mon respect pour les oiseaux et d'avoir veillé avec moi sur les calopsittes sans jamais laisser les labyrinthes administratifs ni les problèmes financiers impacter leur santé. Merci également à Agatha Liévin-Bazin de m'avoir acceptée en stage de Master 1 au sein du laboratoire, et à Sébastien Dérégnaucourt pour avoir défendu mon sujet de thèse lors du jury de l'école doctorale. Merci à l'université Paris Lumière d'avoir accepté de financer un projet dans lequel il était question de musique, d'oiseaux, de xylophones et de grelots. Merci aux membres de mon comité de suivi (et de mon jury de thèse !) : Michel Kreutzer, Maya Gratier et Gilles Gheusi pour leurs conseils éclairés et pour les grands débats passionnés qui ont suivi nos discussions. Merci à Valérie Dufour et Aline Bertin d'avoir accepté d'évaluer mon travail de thèse sans me connaître et de compléter ce jury.

Merci à tous les membres du Laboratoire Ethologie Cognition Développement pour ces années passées ensemble : Pascal Mallet, Nicole Geberzahn, Tudor Draganoiu, Bahia Gellaï et Dominque Herbé. Merci plus particulièrement à Rana Esseily et Anne Bobin-Bègue pour ces deux collaborations inattendues et leurs précieux savoirs sur le développement des enfants, à Laurent Nagle pour les discussions passionnantes, à Nathalie Béguin pour son aide lors des enseignements, à Gérard Leboucher pour ses nombreux conseils et à Mathieu Amy pour son aide en analyses statistiques. Merci aux secrétaires qui se sont succédé et qui ont fait leur possible pour nous faciliter les choses : Josette Gigomas, Sylvie Da Silva, Carine Martinez et Chloé Chardonnel. Merci également aux animalières qui ont toujours été là quand c'était nécessaire et dont l'investissement auprès des oiseaux n'est plus à démontrer : Emmanuelle Martin, Ophélie Bouillet et Marie Huet, sans oublier Philippe et ses talents indispensables de bricoleurs ! Merci aux stagiaires qui m'ont apporté leur aide et leurs nombreuses idées : Alice Al-Asmar, Léa Bouet et Romain Di Stasi. Merci également à mes compagn.on.es de doctorat pour tous les fous rires et le réconfort de notre bureau : les « anciens », Sarah Jeannin, Guillaume Huet des Auney et Rubia Infanti, merci à ceux avec qui j'ai passé ces trois années de thèse, Alice Arraguas, Mylène Augier, Lucille le Maguer et la

relève, Tiffany Volle (on se souviendra longtemps des chercheurs d'or !). Merci tout particulièrement à Uyen Tran, ma compagne de calopsittes, pour avoir partagé avec moi ce lien si particulier avec nos adorables petits monstres à plumes, dans la joie et les fous-rires comme dans la douleur, ainsi qu'à Carla Aimé et Pauline Salvin de m'avoir apporté leurs précieux conseils quand j'en avais besoin, mais aussi pour avoir su me rappeler quand il le fallait que cette thèse était avant tout la mienne.

Un grand merci à l'équipe du Japon de m'avoir accueillie au sein du Centre of Advanced Research on Logic and Sensibility de l'université de Keio : merci à Youcef Bouchekioua pour nos grandes discussions sur la culture niponne et les longues heures de travail à essayer de bricoler ensemble un dispositif adapté, à Matsui, mon crowcatcher officiel, au Professeur E.I. Izawa de m'avoir accepté au sein du laboratoire et bien sûr à Shigeru Watanabe pour sa patience, son sens de l'humour et sa bienveillance tout au long de mon séjour à l'autre bout du monde.

Merci à l'équipe NAC du Centre Hospitalier Vétérinaire de Frégis : les Docteurs Huyn, Zoller et Chassang, de nous avoir aidées à veiller sur les calopsittes nuits et jours et conseillées quand nous en avions besoin.

Merci également à ma famille pour leur soutien permanent : à ma mère de m'avoir appris à ne jamais me décourager (et pour ces superbes collages qui illustrent ma thèse !), à mon père de m'avoir transmis son amour et son respect pour la musique et ceux qui la composent, à mon frère pour son calme inébranlable et son soutien (et son assistance informatique !). Merci à Thomas d'avoir accepté de s'embarquer dans la vie d'une doctorante malgré toutes les angoisses et les aléas que cela comporte et de m'avoir soutenue sans faille dans les moments où j'en avais le plus besoin.

Un immense merci, enfin, à tous les oiseaux dont la vie a croisé la mienne et qui ont su me donner envie de les connaître davantage, des oisillons tombés du nid aux psittaciformes en tous genres qui ont joyeusement réduit en pièces (par ordre d'importance) mes livres, mes vêtements et mes meubles. Merci à Iguazù qui partage ma vie depuis plus de douze ans et qui la partagera encore, j'espère, pendant de longues années. Et merci bien sûr à celles et ceux sans lesquel.le.s ce doctorat n'aurait jamais pu voir le jour : les corbeaux japonais que j'ai renommés aux couleurs des groupes qui ont résonné dans mon casque pendant toutes ces années, Alestorm, Myrath, Avatar, Apocalyptica, Ereb Altor, Kartikeya, Skalmöld et Korpiklaani (avouez que ça sonne quand même mieux que PP, vf ou 27…) et bien sûr les

calos du labo, Wala la gourmande, la farouche Sita, Merlin le chapardeur, le placide Bahloo, la tendre Nephtys, Seth l'aventurier et la petite Isis, Viviane l'indécise, Hermès le bon élève, le volage Loki, Morgane la volontaire, la douce Gaïa et Eole le pot-de-colle, Odin l'explorateur, la sauvage Skadi et Callisto la princesse. Si ce travail doit un jour être utile, j'espère qu'il le sera avant tout pour vous et vos petits congénères à plumes.

Liste des articles composant cette thèse

Effects of listening to music on behaviour and social interactions in cockatiels (*Nymphicus hollandicus*), Mathilde Le Covec, Carla Aimé, T. T. Uyen Tran, Rana Esseily & Dalila Bovet, soumis à *Animal Cognition.*

Is music an evolutionary adaptation? Effects of listening to music on social interactions in preschool children, Carla Aimé, T.T. Uyen Tran, Mathilde Le Covec, Dalila Bovet & Rana Esseily, soumis à *Animal Cognition.*

Musical preferences, indifference to the consonance / dissonance feature and personality in cockatiels, Mathilde Le Covec, Romain Di Stasi, Léa Bouet, Shigeru Watanabe & Dalila Bovet, soumis à *Animal Cognition.*

Musical preferences and influence of music on behaviour in jungle crows, Mathilde Le Covec, Youcef Bouchekioua, Shigeru Watanabe, Ei-Ichi Izawa & Dalila Bovet, soumis à *Behavioural Processes.*

Combinatory sound object play in cockatiels: a forerunner of music? Mathilde Le Covec, Carla Aimé & Dalila Bovet (2019). *Behaviour*. 1:23. DOI: 10.1163/1568539X-00003551

Spontaneous tempo production in cockatiels (*Nymphicus hollandicus*) and jungle crows (*Corvus macrorhyncos*): a prerequisite to produce rhythms. Mathilde Le Covec, Anne Bobin-Bègue, Shigeru Watanabe, Ei-Ichi Izawa & Dalila Bovet, soumis à *Animal Cognition*.

Nous savons qu'à notre mort, ce soleil, ce ciel et cette terre disparaîtront, mais qu'ils continueront à exister sous des formes analogues dans les milieux des générations futures.

Les choses ne se disposent pas seulement dans les deux dimensions de l'espace et du temps. Une troisième dimension s'y ajoute, celles des milieux dans lesquels les objets se répètent selon des formes toujours nouvelles.

En nombre infini, les milieux fournissent, dans cette troisième dimension, le clavier sur lequel la nature joue sa symphonie de signification supra-temporelle et extra-spatiale.

A nous, pendant la vie, de constituer, avec notre milieu, une touche dans le clavier prodigieux sur lequel glisse en se jouant une main invisible.

Jacob von Uexküll, *Mondes animaux et mondes humains* suivi de *La théorie de la signification*, p. 173, Denoël, Paris, (1965).

Toutes les illustrations sont de Blandine Le Covec

Introduction générale

« Quand nous voyons un oiseau mâle étaler orgueilleusement, devant la femelle, ses plumes gracieuses ou ses splendides couleurs, tandis que d'autres oiseaux, moins bien partagés, ne se livrent à aucune démonstration semblable, il est impossible de ne pas admettre que les femelles admirent la beauté des mâles », écrit Darwin (1881, pp. 97-98). Parce qu'elle suggère des similarités entre le sens du beau chez l'humain et les parades chez les animaux, cette phrase remet en cause l'idée selon laquelle seule l'espèce humaine serait sensible à l'esthétique et à l'art. Cette remise en cause est partagée par le philosophe Lestel (2011), pour lequel il est faux de considérer que les animaux ne peuvent avoir aucune activité artistique.

De fait, les origines de l'art pourraient être dérivées, entre autres, de la ritualisation de certains comportements animaux que les humains auraient imités : par exemple dans le cadre de la sélection sexuelle, les chants et les danses des oiseaux montrent un certain nombre de similarités avec ceux des humains (Verpooten & Nelissen, 2009). Ainsi, bien que l'étude de la subjectivité animale soit très compliquée, elle est nécessaire afin de ne pas réduire la psychologie de l'individu qui reçoit le signal à celle d'un automate (Kreutzer & Aebischer, 2015). En plus de soulever un certain nombre de questions éthologiques et cognitives, l'exploration des capacités artistiques chez l'animal non humain peut également nous permettre de mieux comprendre les bases et la phylogenèse de l'art. Ce sujet soulève aussi un certain nombre d'interrogations philosophiques, car ouvrir notre connaissance à d'autres espèces nous pousse à reconsidérer la notion de pratique artistique, mais aussi celle du propre de l'homme.

I. La musique

1. Les origines

La musique est peut-être l'une des plus anciennes formes d'art. Elle est à ce jour présente dans toutes les cultures humaines (Merriam & Merriam, 1964) et de nombreux auteurs

considèrent qu'elle est universellement appréciée (Watanabe et al., 2009 ; McDermott & Hauser, 2005 ; Sugimoto et al., 2010). Il a par exemple été montré que des populations d'origines culturelles différentes étaient capables de reconnaître les émotions primaires induites par de la musique (Balkwill & Thompson, 1999 ; Fritz et al., 2009).

Cette dimension universelle dans la production et la perception de musique soulève un certain nombre de questions quant à son origine et sa valeur adaptative. De ce fait, de nombreuses hypothèses ont tenté d'expliquer son émergence au sein de l'humanité. Cependant, parce que les chants et les rythmes sont immatériels et ne laissent pas forcément de traces physiques, il est difficile de savoir exactement quand et comment la musique est apparue. Pour certains chercheurs, la musicalité serait apparue avant le langage (Mithen, 2005) ; d'autres pensent que musique et langage ne formaient au départ qu'un seul et même moyen de communication, avant de se séparer (Brown, 2000). L'écho est sans doute l'une des premières expériences sonores explorées par les hommes : parce qu'il était supposément relié aux dieux, par ce biais, ils essayaient de communiquer avec lui **(**Rault, 2000**).** Les cavernes, grâce à leurs réverbérations, seraient peut-être les instruments de musique les plus anciens ; certains "points sonores" étaient d'ailleurs indiqués sur les murs (Rault, 2000).

Plus tard, les percussions sont apparues. La plupart du temps il s'agissait d'objets naturels à peine modifiés, troncs, crânes ou bambous avec lesquels les premiers humains ont rythmé leurs danses (Bernardeau et al., 1987). Puis sont venues les flûtes, faites de divers matériaux naturels : les premières flûtes en os seraient apparues il y a plus de 40 000 ans (Fitch, 2006), la plus vieille étant à ce jour datée d'il y a 45 000 ans (Tuniz et al., 2012, voir Figure 1).

Figure 1. Flûte de Divje Babe, plus vieil instrument de musique du monde jamais découvert à ce jour.

Crédit Photo : Musée National de Slovénie.

Les circonstances entourant l'apparition de la musique sont donc, aujourd'hui encore, sujettes à débat.

2. Les hypothèses évolutives

a. Le cheesecake de Pinker

Pour un certain nombre de chercheurs, la musique serait une invention exclusivement culturelle, sans aucune fonction biologique. Pour Pinker (1997) par exemple, la musique n'aurait aucun effet sur la survie ou la reproduction. Tous les éléments qui la composent lui auraient pré-existé, impliqués dans d'autres fonctions communicatives (telles que la transmission des émotions ou le langage). Cette hypothèse est plus communément appelée « l'hypothèse du cheesecake de Pinker », par analogie avec le gâteau du même nom : si la nourriture est indispensable à la survie, la recette du cheesecake, elle, reste une invention culturelle qui ne remplit aucune fonction particulière. Cette hypothèse ne permet cependant pas d'expliquer la présence de musique dans toutes les cultures humaines.

b. L'hypothèse de la sélection sexuelle

Dans "The descent of man" (1881), Darwin fut le premier à expliquer l'expansion de la musique au sein des populations humaines par son aspect adaptatif. Comme le chant des oiseaux, la musique humaine aurait évolué dans un contexte de sélection sexuelle.

Il a été observé qu'au sein d'une même espèce, certains individus de même sexe avaient un meilleur accès reproductif que d'autres à leurs congénères de sexe opposé. Par

conséquent, les traits permettant l'attractivité et l'accès au partenaire pour la reproduction devraient être adaptatifs, au même titre que ceux permettant la survie. La musique pourrait donc avoir évolué car elle améliore le succès reproducteur, en signalant par exemple des qualités importantes à un potentiel partenaire sexuel telles que la coordination et la force (pour la danse), ou la capacité à automatiser des comportements complexes (pour la pratique d'un instrument) (Miller, 2000).

Le terme de « musique » a traditionnellement été appliqué librement au chant des oiseaux. L'utilisation du mot « chant » pour désigner les vocalisations aviaires se retrouve d'ailleurs aussi bien chez les scientifiques que chez les musicologues (Fitch, 2006). Plusieurs compositeurs tels que Mozart, Beethoven ou Messiaen se sont inspirés des oiseaux pour créer des morceaux de musique. De plus, beaucoup d'oiseaux chantent selon des règles précises, qui pourraient être les mêmes que celles qui nous amènent à ressentir des émotions quand nous écoutons de la musique humaine (Rothenberg et al*.,* 2014). Les oiseaux, tout comme les humains, tendent à réduire la monotonie de leurs chants, et il semble que nous sous-estimions souvent leurs aptitudes sonores, puisqu'ils sont capables de percevoir plus de détails que nous sur le plan auditif (Lestel, 2001) : leur résolution temporelle des sons complexes est, par exemple, plus précise que la nôtre (Dooling et al., 2002).

Or chez beaucoup d'espèces d'oiseaux, les chants et les rythmes sont liés à un comportement de parade. Pour ne citer qu'eux, le mâle ménure superbe (*Menura novaehollandiae)* produit des types de chants et de danses selon une séquence prédictible lorsqu'il fait sa cour (Dalziell et al., 2013), les manakins à col d'or (*Manacus vitellinus*) semblent apprendre une suite spécifique de mouvements pour orchestrer leur chorégraphie d'appariement (Coccon et al., 2012), le cordonbleu cyanocéphale (*Uraeginthus cyanocephalus*) produit des danses complexes en claquant ses pattes contre le sol (Ota et al., 2015), les mâles paddas de Java (*Lonchura oryzivora*) coordonnent les claquements de leur bec avec la syntaxe des séquences de leurs notes chantées (Soma & Mori, 2015) et beaucoup de mâles cacatoès noirs (*Probosciger aterrimus*) tambourinent (Heinsohn et al., 2017).

Chez l'être humain la production de musique, parce qu'elle peut être complexe et difficile, indiquerait plusieurs capacités telles que la coordination motrice, l'aptitude à apprendre, la créativité etc. (Miller, 2000). Elle constituerait donc un signal honnête dans le cadre de la sélection sexuelle. Cependant il existe peu de preuves attestant d'un lien entre les capacités musicales et le succès reproducteur au sein de notre espèce. Cette hypothèse n'est donc pas forcément la plus convaincante.

De plus, il a également été montré que les oiseaux pouvaient chanter seuls : certains jeunes semblent s'entraîner pour améliorer leur chant, mais des adultes ont aussi été observés en train de chanter doucement, ce qu'on a qualifié de « chant murmure » (Fitch, 2006). D'autres études ont révélé que chez un certain nombre d'oiseaux, les neurones présents dans l'aire ventrale tegmentale s'activaient lors du chant : le circuit du plaisir est activé quand les oiseaux chantent, et plus encore quand ils le font dans un contexte social (Hara et al., 2007 ; Huang & Hessler, 2008). Cela ouvre d'autres perspectives : les oiseaux pourraient aussi chanter pour leur propre plaisir et être sensibles à l'esthétique qui s'en dégage (Lestel, 2011).

c. Le jeu comme précurseur de la musique

Pour quelques auteurs, le jeu serait un précurseur de la musique.

Fitch (2006) fait remarquer que, dans de nombreuses langues, on parle de « jouer » de la musique, et que la nature créative de cette dernière, ainsi que l'appréciation subjective qui en résulte pour les musiciens comme pour l'audience, justifient ce choix sémantique.

Selon Pellegrini et al. (2007) un comportement de jeu, à l'inverse d'un comportement sérieux, implique que ceux qui le produisent soient plus concernés par le comportement en lui-même que par sa fonction. Sur le plan développemental, les enfants commencent par explorer leur environnement avant de développer ces comportements de jeu qui, par la suite, seront de plus en plus nombreux (Pellegrini et al., 2007). Les jeux induisent l'apparition de conduites innovantes, permettant au juvénile d'échantillonner son environnement (Pellegrini et al., 2007). La sensibilité à la musique apparaît elle aussi très tôt au cours de l'ontogenèse : les préférences pour la musique consonante (Trainor et al., 1998) et la

sensibilité au rythme apparaissent avant l'âge de 6 mois, nous avons donc une prédisposition pour la musique et les pulsations régulières (Zentner & Eerola, 2010).

Il est donc possible qu'un intérêt pour la production de sons lors des comportements de jeu soit précurseur de l'évolution d'un phénomène culturel sonore tel que la musique. En effet, comme le remarquent Cross & Morley (2008), musique et jeu partagent plusieurs caractéristiques. O'Hara & Auersperg (2017) décrivent les comportements de jeu par cinq critères, qui sont largement acceptés : (1) récompensés intrinsèquement, (2) sans objet apparent (3) produits de façon répétée (4) volontairement (5) dans un contexte détendu. Les quatre premiers critères, au moins, peuvent également être appliqués à la musique.

O'Hara & Auersperg (2017) décrivent aussi trois principaux types de jeu : le jeu social, le jeu locomoteur et le jeu d'objet, qui peuvent tous trois être liés à la musicalité. Le jeu social permet aux enfants de développer des comportements sociaux (Pellegrini et al., 2007), et les capacités musicales sont construites sur des mécanismes sociaux importants (Cross & Morley, 2008). Le jeu locomoteur est un comportement de jeu utilisant uniquement le corps. C'est aussi le cas de la danse, qui permet aux enfants de découvrir le corps et ses mouvements possibles et engendre ainsi l'acquisition de capacités motrices spécifiques (Koff, 2012), et de la pratique instrumentale, qui améliore le contrôle des mouvements (Münte et al., 2002). Quant au jeu d'objet, il est défini par l'interaction avec des objets ou la combinaison d'objets entre eux (O'Hara & Auersperg, 2017) *e. g.* via des actions combinatoires, qui les mettent en contact direct les uns avec les autres (Auersperg et al., 2015) ; ce genre de manipulations complexes apparaît dès l'âge de huit mois chez l'enfant (Rat-Rischer et al., 2013) et peut être lié à la pratique d'un instrument.

Musique et jeu permettent également le développement d'une certaine flexibilité cognitive (pour la musique voir Cross & Morley, 2008 ; pour le jeu voir Auersperg et al., 2015, Auersperg et al., 2014a) : selon Stevens (2014) le jeu combinatoire est un processus créatif impliquant une connexion entre les hémisphères et les différentes régions du cerveau ; quant à la musique, elle améliore les interactions entre les deux hémisphères chez les musiciens qui commencent à pratiquer d'un instrument avant l'âge de sept ans (Münte et al., 2002). Enfin Cross & Morley (2008) suggèrent que chez certaines espèces, la musicalité des adultes serait un moyen d'assimiler les modes exploratoires des jeunes. Ce moyen aurait été renforcé par plusieurs facteurs présents chez les espèces nidicoles, et notamment le fait

de vivre avec des populations de plus en plus nombreuses, ayant accès à des modes de reconnaissance, de motivation et de comportements juvéniles.

Chez l'animal non humain, la pratique du jeu permet d'apprendre et de pratiquer des comportements pertinents qui augmentent les chances de survie (O'Hara & Auersperg, 2017). Ces jeux peuvent passer par des manipulations d'objets : des actions combinatoires ont été observées chez les corbeaux de Nouvelle Calédonie (*Corvus moneduloides*), qui combinent les objets qu'ils trouvent dès qu'ils quittent le nid (Rat-Fischer, 2017) et font usage d'outils afin d'interagir avec un nouvel objet (Wimpenny et al., 2011), et les psittaciformes (Auersperg et al., 2015). L'exploration complexe d'objets existe même chez des espèces qui n'utilisent pas d'outils (Gajdon et al., 2014) tels que les grands corbeaux (*Corvus corax*) (Rat-Fischer, 2017). Une étude a également montré des comportements de manipulation et de combinaison d'objets chez un perroquet gris du Gabon (Pepperberg & Shive, 2001).

Enfin l'utilisation d'outil, même si elle ne relève pas directement des comportements de jeu, a déjà été documentée dans le cadre de modifications sonores : c'est par exemple le cas des oecanthinae (*Oecanthus burmeisteri*), des criquets qui intensifient leurs chants en utilisant une feuille comme un baffle sonore (Prozesky-Schulze et al., 1975) et des orangs-outans sauvages (*Pongo pygmaeus wurmbii*), qui baissent la fréquence de leurs cris en insérant des feuilles dans leur bouche afin de paraître plus gros (Hardus et al., 2009).

d. La musique comme renforçateur des liens sociaux

Selon certains auteurs, le cerveau évoluerait pour traiter des informations écologiques telles que la taille du territoire ou la quantité de ressources exploitables (De Casien et al., 2017). Dunbar (1998) lui, pose l'hypothèse du cerveau social et suggère que la grande taille du cerveau des primates refléterait la complexité de leur système social : plus un groupe social est grand, plus on s'attend à ce que ses membres détiennent une capacité importante à traiter des informations concernant les autres individus ; cela leur permet ainsi de s'adapter à la complexité des relations existantes au sein de ce groupe. Également appelée théorie de « l'intelligence machiavélique » (Byrne, 1996), cette hypothèse a, dans un premier temps, surtout été comprise en termes de capacité à tromper ou manipuler (Dunbar

& Schultz, 2007). Aujourd'hui, les phénomènes prosociaux nécessaires à cette intelligence sont cependant de plus en plus étudiés.

La prosocialité est un ensemble de comportements dont les actions bénéficient au receveur sans forcément coûter au donneur. Certains de ces comportements sont favorisés par l'empathie, qui peut être décrite comme un processus complexe au sein duquel des composants cognitifs et affectifs sont impliqués et interagissent. Pour de Waal (2009), c'est la "capacité à communiquer avec les autres, à les comprendre et à faire nôtre leur situation". La découverte des neurones miroir a permis aux chercheurs de voir plus loin : ces neurones possèdent des propriétés motrices et s'activent quand une action est faite, mais aussi quand nous observons quelqu'un faire cette même action (Iacoboni, 2009). Ils auraient donc l'avantage de nous permettre une forme d'intersubjectivité aidant à comprendre l'esprit des autres (Iacoboni, 2009). L'empathie est un processus qui a été sélectionné au fil du temps : elle favorise l'harmonie sociale et la coopération au sein d'un groupe, et toute société trouve son compte à l'exploiter (de Waal, 2009).

Chez l'être humain, musicalité et empathie pourraient entre autres avoir évolué biologiquement et culturellement pour renforcer des liens sociaux permettant la formation de sociétés humaines (Freeman, 1998). Les hominidés ayant vu, au cours de l'évolution, la taille de leurs groupes sociaux augmenter façon importante, ils auraient pu remplacer les toilettages, servant au maintien des bonnes relations et à la stabilité des groupes sociaux chez la plupart des primates non-humains, par la musique, un « toilettage acoustique » plus puissant que le toilettage traditionnel (Dunbar, 2017). Par ailleurs, Falk (2004) et Dissanayake (2000) ont suggéré que la musicalité, parce qu'elle permet une régulation sociale et une certaine union émotionnelle, avait d'abord émergé dans un contexte de communication dyadique mère-bébé. Plusieurs études vont dans le sens de cette hypothèse : non seulement l'intérêt pour la musique se développe dès les premiers jours de vie chez l'être humain (Trehub, 2003), y compris chez des bébés prématurés de 36 semaines (Carvalho et al., 2019) mais en plus, les chants maternels sont étonnamment stables dans leur pitch et leur tempo à travers les cultures (Trehub et al., 1993) et engendrent davantage d'éveil chez les bébés que le langage de la mère (Trehub & Nakata, 2001; Shenfield et al., 2003), ces bébés montrant d'ailleurs plus d'intérêt pour les vidéos sur lesquelles leur mère chante que pour celles sur lesquelles elle parle (Trehub & Nakata, 2001). Cette musicalité

aurait ensuite été étendue à d'autres formes de communication (cérémonies rituelles, parades,…).

Pour Hagen & Bryant (2003), la musique suggérerait l'existence et la qualité d'une coalition ; il a aussi été montré que les chants partageant des fonctions sociales avaient des formes convergentes à travers les cultures (Mehr et al., 2018).

Plusieurs études ont également mis en relief le lien entre musique et comportements sociaux. L'écoute de musique peut notamment avoir des effets positifs sur les auditeurs : les chants religieux induisent un comportement éthique chez les croyants (Lang et al., 2016) et l'écoute de musique en famille et entre pairs contribue à la cohésion au sein d'un groupe (Boer & Abubakar, 2014). Chez des experts de l'improvisation, certaines intentions sociales peuvent également être communiquées via des interactions musicales (Aucouturier & Cannone, 2017). L'expression musicale, à travers la pratique instrumentale, les chants ou la danse, peut aussi induire un renforcement des liens sociaux : chez les enfants, jouer de la musique ensemble améliore les comportements prosociaux (Kirschner & Tomasello, 2010) et l'empathie (Rabinowitch et al., 2012), et les chants des soldats renforcent la solidarité au sein d'un groupe (Cleveland, 1985). La salsa permet à deux danseurs de partager des émotions (Hewer et al., 2010) et Ribeiro (2011) suggère, lui, l'idée de "chorégraphie empathique" : dans l'improvisation, en danse contemporaine, les danseurs ont besoin de comprendre non seulement les intentions et les mouvements de l'autre mais aussi leurs émotions, ce qui implique une certaine empathie.

D'autres études se sont focalisées sur le rythme, l'une des composantes de l'activité musicale. Chez l'être humain, la capacité à se synchroniser à un rythme peut être découpée en trois critères (Patel, 2014) : (1) la prédiction, soit la capacité à anticiper le tempo au lieu d'y réagir, (2) la flexibilité, soit la capacité à s'adapter si le tempo change, et (3) le croisement de modalités, par exemple nous pouvons marquer silencieusement un pulsation à l'écoute d'un rythme. Or cette capacité à se synchroniser pourrait également jouer un rôle positif dans les interactions sociales : partager un rythme contribuerait à la création et au renforcement des liens sociaux au sein d'un groupe (Tarr et al., 2014). Cirelli (2018) a d'ailleurs montré que la synchronie interpersonnelle engendrait des comportements d'aide chez des bébés de 14 mois.

Au sein du règne animal, la prosocialité a notamment été étudiée par le biais du partage alimentaire. Si les différentes fonctions de ce phénomène n'ont pas encore toutes été pleinement comprises, elle peut dans certains cas être compatible avec l'hypothèse de la réciprocité : les deux participants en retireraient un avantage. Le partage alimentaire a donc été étudié chez diverses espèces, et notamment chez les corvidés : les jeunes grands corbeaux communiquent la localisation de carcasses alimentaires à leurs congénères (Heinrich & Marzluff, 1995), des comportements d'alimentation coopérative ont été observés dans un groupe de corneilles noires (Baglione et al., 2002) et la présence d'une aide prosociale dans un cadre alimentaire (transfert d'un jeton permettant d'obtenir une récompense à un autre oiseau) a été documentée chez les grands corbeaux (Massen et al., 2015). Cette coopération alimentaire peut notamment avoir lieu avec le partenaire sexuel chez les corbeaux freux (*Corvus frugilegus*) (Clayton & Emery, 2007) et les choucas (von Bayern et al., 2007), pour lesquels ce partage faciliterait la formation du lien social et serait un précurseur à l'établissement des couples. On a de plus montré que les perroquets gris du Gabon (*Psittacus erithacus)* pouvaient eux aussi faire preuve de réciprocité, et que la relation entre les oiseaux jouait probablement un rôle au sein de ces interactions (Péron et al., 2013), tout comme chez les calopsittes élégantes (*Nymphicus hollandicus*), pour lesquelles le partage alimentaire est influencé par les affinités et les liens de parenté (Liévin-Bazin et al., 2019).

L'influence de la musique sur les comportements interactifs a moins été étudiée chez l'animal non-humain ; certaines études se sont malgré tout penchées sur le sujet. Notamment, les chimpanzés de laboratoire montrent plus de comportements affiliatifs lorsqu'ils écoutent de la musique instrumentale et moins de comportements agonistiques quand ils écoutent de la musique vocale (Videan et al., 2007), et des gorilles (*Gorilla gorilla gorilla*) en zoo agressent moins leurs congénères quand ils écoutent de la musique classique (Wells et al., 2006). Chez la souris (Angelucci et al., 2007), l'exposition à la musique module l'activité de l'hippocampe, une structure cérébrale qui joue un rôle majeur dans le traitement des émotions, y compris les émotions sociales (Immordino-Yang & Singh, 2013).

Musique et empathie pourraient donc avoir évolué pour améliorer la coopération et la cohésion au sein d'un groupe.

e. L'apprentissage vocal : un facilitateur de la musicalité ?

Parce qu'ils sont phylogénétiquement très proches de nous, les primates sont des modèles intéressants, qui peuvent permettre de comprendre comment un trait spécifique est apparu et a évolué au sein de l'espèce humaine. Pour Emery (2004), les grands singes ont d'ailleurs toujours bénéficié d'une position particulière en raison de leurs relations phylogénétiques avec les humains.

C'est la raison pour laquelle quelques recherches sur la musicalité ont déjà été conduites avec des primates. Ces recherches montrent que les macaques (*Macaca mulatta*) sont capables de synchroniser les battements de leur main avec un métronome (Zarco et al., 2009) et que ouistitis (*Callithrix jacchus*) et tamarins (*Saguinus oedipus*) montrent des préférences pour les tempi lents plutôt que rapides (McDermott & Hauser, 2007). Les chimpanzés préfèrent la musique africaine et indienne au silence (Mingle et al., 2014) et une étude d'Hattori et al. (2013) présente une femelle chimpanzé capable de synchroniser les battements de sa main avec un son entendu. Un bébé femelle chimpanzé élevé par des humains a également montré une préférence pour la consonance par rapport à la dissonance (Sugimoto et al., 2010). Quant au tambourinage, il a été observé dans la nature chez plusieurs mâles chimpanzés (Babiszewska et al., 2014) mais aussi chez un mâle captif, Barney, dont la performance suivait la structure et les traits que l'on peut retrouver dans un contexte de tambourinage musical humain (Dufour et al., 2015).

Cependant le nombre d'exemples est faible, et tend à montrer que les primates ne sont peut-être pas aussi intéressés par la musique que nous aurions pu le penser au vu de leur proximité génétique avec nous. En effet, macaques et chimpanzés ont besoin d'un très long apprentissage (jusqu'à un an) avant de pouvoir se synchroniser à un rythme (Zarco et al., 2009 ; Hattori et al., 2013), et ils le font avec moins de précision et plus de variabilité temporelle que les humains (Zarco et al., 2009) ; quant aux ouistitis et tamarins, ils préfèrent le silence à la musique (McDermott & Hauser, 2007), tout comme les orangs-outans (Ritvo & McDonald, 2016). De plus, une étude complémentaire au cas de Barney n'a trouvé chez les autres singes de la colonie aucun épisode rythmique qui aurait pu correspondre aux critères

d'une production musicale (Dufour et al., 2017). Par ailleurs, dans la nature, certains comportements de tambourinages spontanés ont été observés chez des chimpanzés (*Pan troglodytes*), qui frappent les racines des arbres, (Arcadi et al., 1998), ou chez des gorilles (respectivement *Gorilla gorilla gorilla* et *Gorilla beringei beringei*), qui se frappent le torse (Schaller, 1963) ou tapent leurs mains l'une contre l'autre (Kalan & Rainey, 2009) ; cependant la régularité de ces coups n'a pas été analysée, il est donc difficile de savoir s'il s'agit d'un tempo ou pas.

Ce manque de sensibilité musicale pourrait être lié aux faibles capacités d'apprentissage vocal des primates non humains, chez lesquels il y a en effet peu de preuves d'apprentissage de vocalisations complexes (Janik & Slater, 1997).

Certains éléments tendent à montrer que la capacité à imiter des sons serait une aptitude cognitive complexe se basant sur l'apprentissage, la mémoire et l'attention, mais aussi sur des mécanismes de contrôle vocal qui impliquent des représentations événementielles multimodales, dépendantes de l'expérience (Mercado et al., 2014). L'apprentissage vocal est un processus par lequel la production vocale est modifiée en fonction de l'expérience auditive (Marler, 1976) et plus spécifiquement selon des informations auditives externes (Schusterman, 2008). Watanabe lie ce trait à une certaine sensibilité à la musique (Watanabe et al., 2009) : un stimulus musical serait essentiellement renforçateur chez les espèces qui apprennent des stimulations auditives complexes pendant leur ontogenèse. Cette capacité d'apprentissage vocal serait également un pré-requis à la capacité à suivre un rythme (Patel et al., 2009) : pour plusieurs auteurs, l'apprentissage vocal serait lié au contrôle moteur (*e. g.* Janik & Slater, 1997 ; Jarvis, 2013) ; il dépend d'ailleurs en partie du système vocal moteur, un ensemble de circuits de contrôle neuronaux et de muscles associés dont les actions coordonnées servent à produire des sons (Mercado et al., 2014). Sur le plan cérébral, les connections entre les régions auditives et les régions de planification motrices seraient plus importantes chez les humains que chez les autres primates, parce qu'ils sont capables d'apprentissage vocal (Patel & Iversen, 2014). De fait, un lien s'établit dès la douzième semaine de gestation entre le développement vocal et le développement moteur (de Vries et al., 1985) ; cette coordination voco-motrice permet chez les bébés de

développer ce qui deviendra les gestes co-verbaux (les gestes accompagnant la parole) chez les adultes (Iverson, 2010).

Parmi les mammifères, en plus des êtres humains, éléphants, cétacés, pinnipèdes et chauves-souris sont les seuls à démontrer cette aptitude.

Un certain nombre d'études ont mis en évidence le niveau discriminatif (*i. e.* la capacité à discriminer deux stimuli) de la musique ou du rythme chez de nombreuses espèces non humaines telles que, pour la musique, les éléphants (*Elephas maximus*) (Reinert, 1957), les rats (*Rattus norvegicus*) (Poli & Previde, 1991 ; Otsuka et al., 2009), les pigeons (*Columba livia*) (Porter & Neuringer, 1984), les étourneaux (*Sturnus vulgaris*) (Hulse et al., 1995), les paddas de Java (Watanabe & Nemoto, 1998), les macaques japonais (*Macaca fuscata*) (Izumi, 2000), les carpes (*Cyprinus carpio*) (Chase, 2001) et les poissons rouges (*Carassius auratus*) (Shinozuka et al., 2013), et pour le rythme les étourneaux (Hulse & al., 1984), les diamants mandarins (*Taeniopygia guttata*), les perruches ondulées (*Melopsittacus undulatus*) (ten Cate et al., 2016) et deux choucas (*Corvus monedula*) (Reinert, 1965). Cependant, peu d'entre elles constatent un réel effet renforçateur de la musique.

Par exemple des animaux qui ne sont pas ou peu capables d'apprentissage vocal, tels que les pigeons (Watanabe & Nemoto, 2009), les poules (*Gallus gallus domesticus*) (McAdie et al., 1993), les rats (Crespo-Bojorque & Toro, 2015) ou les poissons rouges (Shinozuka et al., 2013) ne montrent pas de préférences musicales marquées, à l'inverse d'oiseaux capables d'apprentissage vocal : les paddas de Java préfèrent la musique au silence et restent plus longtemps sur les perchoirs diffusant de la musique classique (Bach et Vivaldi) que de la musique moderne (Schöenberg et Carter) (Watanabe & Nemoto, 1998), et une étude avec des gris du Gabon (*Psittacus erithacus*) a montré que, face à un écran tactile leur laissant le choix entre déclencher un morceau de musique rythmé ou un morceau de musique calme, les perroquets avaient des préférences stables, mais différentes selon les individus (Péron et al., 2013). D'autres espèces capables d'apprentissage vocal ont montré certaines aptitudes musicales : c'est par exemple le cas des bouvreuils pivoine (*Pyrrhula pyrrhula*), connus pour apprendre des mélodies que leur enseignent des humains et qui sifflent certains morceaux de musique, mais sont aussi capables d'anticiper de façon synchronisée la suite de ces morceaux (Nicolai et al., 2013) et de Theo, une femelle perroquet gris du Gabon, qui s'est

montrée capable de chanter en réponse à un stimulus musical et de généraliser les règles de la musique qu'elle entendait à d'autres notes (Bottoni et al., 2003).

Quant à la capacité à se synchroniser à un rythme, elle a souvent été considérée comme propre à l'homme (Bispham, 2006; Brown, 2006; Thaut, 2003). Comme il a été décrit plus haut, les études effectuées avec les primates se sont montrées peu convaincantes (voir Zarco et al., 2009 et Hattori et al., 2013). À l'inverse, plusieurs espèces capables d'apprentissage vocal montrent, une fois de plus, des aptitudes certaines dans ce domaine. Une étude a par exemple montré qu'une otarie de Californie (*Zalophus californianus*) pouvait se synchroniser à une pulsation (Cook et al., 2013), cependant il subsiste des doutes sur la présence de cette capacité d'apprentissage vocal chez les otaries : en 1969 peu d'éléments allaient en ce sens (Peterson & Bartholomew) mais une étude plus récente révèle qu'il y a de plus en plus de preuves en faveur de la capacité d'apprentissage vocal chez cet animal (Reichmuth & Casey, 2014). Une autre étude a montré qu'un éléphant avait produit un battement stable sur un tambour (Patel & Iversen, 2006). Plusieurs espèces de psittaciformes dansent spontanément en rythme (Fitch, 2009) à travers un large panel de tempi (Patel et al., 2009) : c'est le cas pour au moins six espèces d'entre eux (Schachner et al., 2009) ; les perruches ondulées (*Melopsittacus undulatus*) peuvent également se synchroniser avec un métronome (Hasegawa et al., 2011) . Le cacatoès Snowball (voir Figure 2.) s'est même montré capable de danser en rythme selon un répertoire comprenant 14 mouvements, dont deux composés (Jao Keehn et al., 2019). Plus surprenant encore, les cacatoès noirs créent des outils avec lesquels ils rythment sur des troncs creux (Wood, 1984) suivant des styles qui leur sont propres, produisant ainsi des pulsations régulières et des composantes répétées dans un contexte donné : ils partagent des rudiments clefs de la musique humaine instrumentale (Heinsohn et al., 2017). La synchronisation rythmique pourrait donc avoir des fondations neurobiologiques communes chez les humains et les oiseaux (Patel et al., 2009).

Enfin, comme il a été expliqué au-dessus (voir le paragraphe sur l'hypothèse de la sélection sexuelle), plusieurs études ont établi un parallèle entre le chant des oiseaux et la musique humaine.

Figure 2. Le perroquet danseur Snowball, qui a engendré plusieurs études sur le rythme chez les psittaciformes.

Crédit photo : Irena Schulz, Bird Lovers Only Rescue Inc.

Or il se trouve qu'au sein du règne animal, peu d'espèces sont capables d'apprendre des stimuli vocaux (Patel et al., 2009). L'apprentissage vocal a néanmoins évolué de façon convergente chez au moins trois groupes d'oiseaux : les passeriformes (oiseaux chanteurs), les psittaciformes (perroquets) et les trochilidés (colibris), qui doivent apprendre à produire des chants ou certains signaux de communication complexes au cours de leur ontogenèse (Fitch, 2006). Passeriformes, psittaciformes et trochilidés comptent pour presque la moitié des espèces d'oiseaux du monde (Fitch, 2006) et ont, au sein de la partie avant de leur cortex, des noyaux qui n'ont, jusqu'ici, pas été découverts chez les autres groupes d'oiseaux (Petkov et Jarvis, 2012). Il y aurait même, chez les perroquets et certains oiseaux chanteurs, deux niveaux d'imitation vocale : une forme basique et associative partagée avec la plupart des passereaux, soit le fait de copier le chant de ses voisins, et une forme plus complexe, qui permettrait d'imiter des sons isolés (Moore, 2003). Selon Fischetti (2007) p. 126 : « Si nous sommes génétiquement plus proches des chimpanzés, d'une certaine manière nous sommes vocalement plus proches des oiseaux […]. ».

3. Une possible évolution convergente entre humains et oiseaux ?

Il s'avère donc que les oiseaux et les humains partagent certaines caractéristiques musicales. Comme il a déjà été mentionné au-dessus (voir le paragraphe sur l'hypothèse de l'apprentissage vocal), ces caractéristiques semblent plus limitées chez les primates non humains, malgré leur proximité génétique avec les êtres humains. Il est donc improbable que la musicalité ait évolué chez un ancêtre commun aux oiseaux et aux humains ; à l'inverse elle aurait pu évoluer deux fois : chez les humains et chez les oiseaux. Il s'agirait donc d'un cas d'évolution convergente facilitée par les capacités d'apprentissage vocal. Autrement dit, musicalité et apprentissage vocal pourraient être des traits analogues (Fitch, 2006) *:* des traits similaires qui n'étaient pas présents chez un ancêtre commun, mais ont évolué de façon indépendante dans deux lignages.

II. Étudier la musique au sein du règne animal

Comme nous l'avons développé précédemment, plusieurs forces sélectives ont sans doute permis l'apparition de la musique, et une étude comparative entre les espèces pourrait nous aider à mieux comprendre cette évolution.

Cependant, l'étude scientifique de l'art n'est pas toujours aisée.

Marquand (2016) a détaillé trois façon d'étudier l'art : (1) la méthode mystique, qui consiste à considérer que l'art est un mystère qui ne peut qu'être appréhendé et admiré mais pas compris, (2) la méthode métaphysique, qui considère l'art comme une forme de philosophie active pouvant être expliqué par les idées produites par cette philosophie et (3) la méthode scientifique, qui consiste à tirer des lois de l'étude d'objets d'arts et à les appliquer à des cas similaires.

La difficulté à définir l'art complique cependant les choses : la définition de l'art est controversée au sein de la philosophie contemporaine ; cette controverse s'étend jusqu'à la potentialité même de définir l'art, certains considérant que ce serait inutile (Adaijan, 2012).

Ces considérations s'appliquent aussi à la musique. Pour plusieurs auteurs (Fitch, 2006 ; Ravignani et al., 2014), la concevoir comme un tout indifférencié risquerait d'omettre qu'elle intègre une large variété de domaines pouvant servir des buts divers : les interrogations portant sur ses origines, ou sa fonction, ne pourraient se contenter d'une seule réponse. Une stratégie consistant à diviser la musique en différents éléments, qui permettrait d'affronter sa nature multi-composée, serait alors plus pertinente (Ravignani et al., 2014). Nous savons en effet que la musique est basée sur un set de mécanismes cognitifs qui interagissent et ont leur propres bases neuronales (Ravignani et al., 2014) et de mécanismes perceptuels ayant une très longue histoire évolutive, pour certains partagés avec la majorité des autres vertébrés (Fitch, 2006) : la perception de la mélodie, par exemple, serait sous-tendue chez l'humain comme chez les autres espèces par plusieurs stratégies perceptuelles (l'oreille relative et l'oreille absolue en sont un exemple) (Hulse et al.,1992).

La musique peut également être étudiée via le concept de musicalité, qui est plus large et sans doute plus facile à explorer chez l'animal non humain. La musicalité a été décrite par Hoeschele et al. (2015) comme « la capacité qui nous permet de percevoir, d'apprécier et de produire de la musique ».

1. Quels critères étudier chez l'animal non humain ?

Certains auteurs ont essayé de définir des critères permettant d'étudier musique et musicalité chez l'animal non-humain.

Pour Arom (2007), l'idée d'un continuum du vivant englobant la musique suscite la question des critères de ce que nous qualifions de musique. Arom (2007) définit donc plusieurs « universaux musicaux », des caractéristiques de la musique produite par les humains : (1) la présence d'une intentionnalité, pour celui qui agit et pour les membres de sa culture, (2) la notion de processus formel, autrement dit la musique serait le résultat d'une convention, (3) la présence de ratios temporels, c'est-à-dire d'une pulsation, qui se base sur la notion de périodicité, (4) la présence de symétrie, dans la mesure où la musique serait une recherche d'équilibre : un morceau alterne par exemple entre solistes et chœurs, (5) la référence à une échelle musicale, soit des hauteurs contrastives sélectionnées dans le continuum sonore : c'est par exemple le cas de la gamme pentatonique, (6) la présence

d'une répartition des rôles lorsque plus d'un individu est impliqué, (7) la présence de catégories ou répertoires, autrement dit la signification symbolique attribuée à telle ou telle production. Arom (2007) explique que chaque musique humaine regroupe au minimum deux de ces critères ; la question se pose alors de savoir si certains de ces critères peuvent se retrouver dans une production animale sonore.

Watanabe & Kuczaj (2013) proposent, eux, de discuter les comportements esthétiques des animaux sous trois aspects : (1) cognitif, soit la capacité de discrimination, (2) plaisir, soit la notion de renforcement, (3) créativité, soit la question des habilités motrices. Cette conception de la créativité nous semblant incomplète, nous prenons le parti d'en utiliser une plus cognitive : pour Runco & Jaeger (2012), dans sa définition standard, la créativité implique d'une part l'originalité (autrement dit la conception de quelque chose de nouveau ou d'inhabituel) et d'autre part l'effectivité. Otsuka et al. (2009) étudient la musicalité à trois niveaux, les deux premiers étant identiques à ceux de Watanabe & Kuczaj : (1) discriminatif, soit la capacité à discriminer deux types de musiques différentes, (2) renforçateur, soit la capacité à percevoir la musique comme un stimulus agréable, (3) facilitateur/inhibiteur, soit la possibilité d'être influencé positivement ou négativement par la musique.

Enfin Gupfinger & Kaltenbrunner (2018) passent en revue différents projets musicaux, et définissent ainsi 4 types de projets musicaux impliquant des animaux, en fonction de la compréhension musicale et des capacités cognitives et auditives qui lui sont associées chez l'espèce animale observée :

(1) *les mouvements animaux comme sources de contrôle*, ce qui implique des formes de vie qualifiées de simples telles que les bactéries ou autres animaux simples (vers de terre), les animaux ne jouant ici qu'un rôle passif puisqu'ils n'ont aucune interaction directe avec les équipements qui engendrent du son, ce sont donc leurs mouvements qui produisent une forme de musique sans volonté de leur part,

(2) *les animaux comme performeurs inconscients*, lorsque ces derniers touchent ou déclenchent les interfaces, instruments ou capteurs et ont donc des interactions directes avec les équipements, mais manquent de la cognition nécessaire pour comprendre la causalité de leurs actions en lien avec les résultats musicaux

(3) *les animaux comme musiciens entraînés* lorsqu'ils deviennent des performeurs musicaux actifs, comme on en voit par exemple beaucoup sur internet jouer des instruments de musique, la plupart du temps après un entraînement

(4) *les animaux comme musiciens volontaires*, comme c'est par exemple le cas du projet *metamusic* d'Alien production, présenté par l'article, qui développe des installations sonores interactives pour les animaux captifs, par l'intermédiaire d'un large panel de capteurs et d'outils que les animaux sont capables d'explorer, et avec lesquels ils peuvent jouer.

Ces différents critères peuvent être utiles dès lors que l'on s'intéresse à l'étude de la musicalité au sein du règne animal. Dans le cadre de ce doctorat, nous prenons donc le parti de nous intéresser à une définition de la musique élargie à la musicalité, et de nous interroger sur les critères de cette musicalité que remplissent les animaux non-humains.

Il reste cependant, dans ce cadre, à choisir un modèle pertinent. Comme cela a déjà été suggéré plus haut, les oiseaux pourraient être de bons candidats en la matière.

2. Des singes à plumes

Les structures correspondant au neocortex cérébral des mammifères, une région considérée comme primordiale pour les hautes capacités cognitives, ne sont que peu développées chez les oiseaux (Lui et al., 2011). Selon Emery (2006), cela aurait mené certains neurologistes à croire que ces derniers étaient des créatures instinctives relativement peu capables d'apprentissage.

Pourtant, des études effectuées chez certaines espèces d'oiseaux démontrent le contraire. Psittaciformes et corvidés sont notamment souvent comparés entre eux dans le domaine de la cognition aviaire (pour une revue exhaustive voir Lambert et al., 2019), ces deux catégories d'oiseaux ayant même gagné le surnom de "grands singes à plumes" (Emery, 2004) en raison de capacités cognitives défiant celles des singes anthropoïdes (Emery, 2006).

Psittaciformes et corvidés ont développé des élargissements cérébraux sous-tendant leur cognition complexe : ce processus évolutif est probablement basé sur des structures sous-jacentes communes aux grands singes et aux cétacés (Osvath et al., 2014). Plus spécifiquement, des études récentes ont montré une convergence des circuits neuronaux entre le cortex préfrontal et le neopallium caudiolatéral (Güntürkün, 2005; Jarvis et al.,

2005), appuyant l'idée d'une cognition comparable entre psittaciformes, corvidés et grands singes. Plus encore, ces deux catégories d'oiseaux ont un nombre de neurones supérieur à celui des grands singes au niveau du télencéphale alors que dans la plupart des cas, la taille absolue de leur cerveau est moindre (Olkowicz et al., 2016) : cette haute densité neuronale serait à la base de l'intelligence aviaire.

Nous avons également vu précédemment que, chez les primates, la grande taille du cerveau, et donc les capacités cognitives, serait liée à la complexité de leur système social (Dunbar, 1998). Cependant chez les oiseaux, la relation potentielle entre sociabilité et taille du cerveau est complexe et toute comparaison avec les primates doit être prise avec précaution. Les systèmes sociaux aviaires sont flexibles, la taille du groupe n'est donc pas forcément un bon indicateur (Emery et al., 2007). Le système d'appariement, en revanche, pourrait avoir une grande importance : Emery et al. (2007) relèvent que d'une manière générale, les espèces d'oiseaux formant des couples à vie, comme c'est le cas des psittaciformes et des corvidés, sont aussi celles dont les individus ont le plus gros cerveau relativement à la taille de leur corps. Chez les oiseaux monogames à long terme, le lien entre les partenaires nécessite en effet une intelligence de la relation qui permettrait à chacun de comprendre les signaux de l'autre, de lui répondre de façon appropriée et de prédire ses comportements, ce qui engendrerait une relation stable avec des bénéfices mutuels (Emery et al., 2007).

Psittaciformes et corvidés sont également de très bons modèles pour tester les différentes hypothèses évolutives évoquées ci-dessus.

Tout d'abord, chez la plupart des espèces d'oiseaux, les chants et les rythmes ont été observés en majorité lors de la saison des parades (Searcy & Andersson, 1986) comme c'est par exemple le cas des canaris (*Serinus canaria)*, qui ont tendance à produire plus de « phrases sexy » (une phrase vocale spécialement appréciée des femelles, Vallet & Kreutzer, 1995) pendant la période de reproduction (Leitner et al., 2001) et des cacatoès noirs, dont le tambourinage est supposément un comportement de parade (Heinsohn et al., 2017). Psittaciformes et passeriformes (dont font partie les corvidés) sont donc de bons modèles pour tester l'hypothèse de la musicalité en tant que trait favorisé par la sélection sexuelle.

D'autre part, ces deux groupes d'oiseaux ont démontré certains comportements qui permettraient de s'intéresser à l'hypothèse du jeu comme précurseur de la musique : psittaciformes et corvidés montrent une nature joueuse qui développe leur capacité à explorer leur environnement et à résoudre des problèmes (voir Auersperg, 2015 pour une discussion). Certains jeux comprennent des actions combinatoires chez les corvidés (Rat-Fischer, 2017) et plusieurs espèces de psittaciformes maintiennent des comportements de jeux d'objets à l'âge adulte (Auersperg et al., 2014a, 2015). De plus, corvidés et psittaciformes peuvent utiliser les outils : c'est notamment le cas des corbeaux de Nouvelle Calédonie (Wimpenny et al., 2011), des grands corbeaux (*Corvus Corax*), de la corneille d'Amérique (*Corvus brachyrhynchos*), des corbeaux freux (*Corvus frugilegus*) (pour une revue voir Lambert et al., des 2019), des cacatoès de Goffin (*Cacatua goffiniana*) (Auersperg et al., 2012), des cacatoès noirs (Wood, 1984 ; Heinsohn et al., 2017), des kéas (*Nestor notabilis*) (Auersperg et al., 2011; Gajdon et al., 2011) et des aras hyacinthes (*Anodorhynchus hyacinthinus*) (Borsari & Ottoni, 2005).

Par ailleurs, l'hypothèse de la musique comme renforçateur des liens sociaux pourrait également être évaluée avec ces deux groupes d'oiseaux. Comme détaillé ci-dessus, différents comportements de prosocialité et d'empathie ont déjà été observés chez les corvidés (Heinrich & Marzluff 1995 ; Baglione et al., 2002 ; Clayton & Emery, 2007 ; von Bayern et al., 2007 ; Fraser & Bugnyar, 2010 ; Massen et al., 2015) et les psittaciformes (Péron et al., 2013 ; Liévin-Bazin et al., 2019). De plus, la relation entre vocalisations et renforcement des liens sociaux a déjà été documentée. Chez certains passeriformes, les duos de chants renforcent le couple parce qu'ils facilitent la surveillance du partenaire, la défense conjointe du territoire et la synchronisation au niveau de l'élevage des jeunes (Sonnenschein & Reyer, 1983), chez les corbeaux freux par exemple les cris permettraient de renforcer et de maintenir la relation de couple (Røskaft & Espmark, 1982). Chez les perroquets, les duos sont utilisés pour la défense conjointe du territoire (par exemple chez les Amazones à nuque d'or (*Amazona auropalliata*), Dahlin & Whright, 2012) et la concordance vocale (le fait d'imiter divers cris produits par d'autres individus) permet une forme de négociation entre les individus de deux groupes différents (Balsby & Bradbury, 2009). Danser en rythme pourrait également être lié aux actions sociales, puisque les perroquets sont des oiseaux grégaires (Fitch, 2009) : Jao Keehn et al. (2019) remarquent que

chez le cacatoès Snowball, danser semble être un comportement social utilisé afin d'interagir avec les humains qui s'occupent de lui (soit son groupe de substitution).

Enfin , psittaciformes et passeriformes sont capables d'apprentissage vocal toute leur vie quel que soit leur sexe et ce dans différents contextes (Lambert et al., 2019) et montrent, pour les psittaciformes et certains passeriformes, des aptitudes musicales certaines en terme de production sonore (Nicolai et al., 2013 pour les passeriformes; Bottoni et al., 2003 pour les perroquets) et rythmique (Heinsohn et al., 2017 pour les psittaciformes), de synchronisation (Schachner et al., 2009 et Hasegawa et al., 2011 pour les psittaciformes) et de préférences musicales (Watanabe & Nemoto, 1998 pour les passeriformes ; Péron et al., 2013 pour les psittaciformes).

3. Des implications pour le bien-être animal

Il a été montré que la musique pouvait influencer positivement les émotions de certains animaux non-humains : chez les rats, cela déclenche une augmentation de la synthèse de calcium et de dopamine, suggérant que cela pourrait diminuer les symptômes des maladies impliquant des dysfonctionnements de la dopamine (Sutoo & Akiyama, 2004), et des changements physiologiques bénéfiques ont été observés chez les chiens (*Canus lupus familiaris*) en réponse à la musique, impliquant une diminution de leur niveau de stress (Bowman et al., 2017). Toujours chez les chiens, la musique classique réduit le niveau de stress (Kogan et al., 2012) et les aboiements, et augmente le temps passé à se reposer (Wells et al., 2002). La thérapie par la harpe permet aussi de diminuer leur vitesse de respiration, l'hyperactivité et l'anxiété (Boone & Quelch, 2003). La diffusion de musique permet également une diminution de comportements stéréotypés chez des éléphants d'Asie vivant en zoo (Wells & Irwin, 2008) ou encore une augmentation des comportements sociaux comme le toilettage, le jeu et l'exploration chez des chimpanzés (Howell et al., 2003).

Les possibilités d'application de la musique sont donc nombreuses, notamment dans le cadre du bien-être et de l'enrichissement d'animaux en captivité, raison pour laquelle il est important de vérifier si certaines espèces apprécient la musique, et si oui, laquelle. Il est de plus à noter que des millions de perroquets et de perruches sont possédés comme animaux de compagnie dans le monde.

III. Modèles animaux et collaborations

Cette thèse a été effectuée avec des psittaciformes, les calopsittes élégantes, et des corvidés, les corbeaux à gros becs (*Corvus macrorhynchos*).

Psittaciformes et corvidés partagent un certain nombre de points communs : en plus de connaître une période de développement importante avant de devenir adultes, ils vivent longtemps (19 ans pour un corbeau à gros bec et 20 ans pour une calopsitte élégante par exemple) et sont confrontés à de nombreux problèmes écologiques : entre autres, ils évoluent constamment dans des environnements variables et la plupart des espèces montrent des niveaux de complexité sociale similaires à celle des grands singes (Emery, 2006).

À notre connaissance, peu d'études comparatives ont été réalisées entre les psittaciformes et les corvidés, et aucune étude s'intéressant à la musicalité n'a été effectuée chez les perruches calopsittes ni les corbeaux à gros becs.

1. Modèles animaux

a. Les calopsittes élégantes

Les calopsittes élégantes (voir Figure 3.) sont des cacatuidés (soit des perruches de la même famille que les cacatoès) originaires d'Australie, appartenant à l'ordre des psittaciformes. Elles évoluent en groupe pouvant comprendre plusieurs dizaines d'individus et vivent jusqu'à vingt ans en captivité. Elles sont monogames et gardent le même partenaire toute leur vie. Leur poids moyen se situe entre 80 et 100 grammes pour une taille allant de 30 à 35 cm. Ces perruches sont domestiques et faciles à héberger, notamment grâce à leur tolérance sociale très élevée.

Figure 3. Calopsittes élégantes (Nephtys et Seth), LECD (France)

Crédit Photo : Mathilde Le Covec

Plusieurs études se sont intéressées aux couples formés par les calopsittes. D'une manière générale, il y a peu de différences comportementales entre les mâles et les femelles, que ce soit au sein du couple ou en dehors (Spoon et al., 2004). Concernant la couvaison et l'élevage des jeunes, les soins sont biparentaux et la coordination au sein du couple est primordiale pour le succès reproducteur : plus la compatibilité et la coordination sont importantes, meilleur est le succès reproducteur (Spoon et al., 2006). L'expérience reproductive des mâles comme des femelles joue un rôle dans le succès reproducteur, avec une prévalence cependant pour l'expérience reproductive des femelles (plus les femelles sont expérimentées, plus le succès reproducteur du couple est grand) (Stone et al., 1999). Seibert et al. (2001) font également état d'une certaine variabilité dans la composition des groupes d'individus étudiés lors de la nidification : en plus des couples de calopsittes habituelles, une triade et des accouplements extra-couples ont été observées. Par ailleurs, les calopsittes restent en couple même en dehors de la période de reproduction (Spoon et al., 2006). Les interactions sociales varient en fonction des couples et reflètent le degré de compatibilité comportementale entre les partenaires : plus leurs comportements sont affiliatifs et concordants, moins ils montrent de comportements agressifs et discordants, et vice versa (Spoon et al., 2004). Cette compatibilité intra-couple ainsi que les qualités individuelles ont une influence sur la stabilité du couple, et peuvent jouer un rôle dans le maintien ou la dissolution d'une relation (Spoon et al., 2007). Les partenaires de couple ont de meilleures interactions, sont plus synchronisés, s'agressent moins, se toilettent plus et

ont davantage de comportements sexuels que les individus qui ne sont pas en couple (Spoon et al., 2004).

Seibert et al. (2001) ont aussi montré que les mâles étaient plus agressifs que les femelles, qu'ils étaient plus élevés que les femelles dans la hiérarchie et qu'ils s'engageaient davantage dans des comportements de toilettage avec les femelles qu'avec d'autres mâles.

Une étude s'est également intéressée aux capacités cognitives chez une calopsitte (Pepperberg & Funk, 1990). Elle porte sur la permanence de l'objet et la tâche A-non-B, une tâche au cours de laquelle un objet localisé à un point A lors de plusieurs essais successifs est ensuite déplacé à un point B de façon visible (étape 1) ou invisible (étape 2). On regarde alors si l'animal fait l'erreur de continuer à le chercher en A. La calopsitte s'est montrée capable de passer les deux étapes de la tâche A-non-B avec succès.

Par ailleurs une étude effectuée au Laboratoire Ethologie Cognition Développement (également encadrée par Dalila Bovet, avec les mêmes oiseaux que ceux de ce travail de thèse) s'est intéressée au partage alimentaire et aux comportements affiliatifs (les toilettages mutuels) chez les calopsittes élégantes (Liévin-Bazin et al., 2019). L'étude a montré que les calopsittes partagent de la nourriture avec différents partenaires au moins jusqu'à leur troisième année de vie, bien que la fréquence de ces partages ainsi que le nombre de partenaires diminuent avec le temps. Les calopsittes partagent également plus avec leurs frères et sœurs qu'avec d'autres congénères, mais sont plus enclins à partager avec des individus du sexe opposé. De plus, les jeunes partagent plus avec ceux qui ont préalablement partagé avec eux, ce qui suggère de la réciprocité. C'est également le cas, dans une moindre mesure, pour les toilettages mutuels.

Lors d'une autre étude effectuée au laboratoire, des cris de détresse ont été diffusés aux calopsittes. Les résultats ont montré que ces dernières étaient capables de contagion émotionnelle et qu'elles montraient plus de stress quand elles étaient affiliées à l'oiseau dont on leur diffusait le cri de détresse (Liévin-Bazin et al., 2018).

Enfin, Seki (2018) s'est intéressé aux calopsittes en tant que modèle animal pour l'étude de l'évolution de la musique. Il a élevé quatre poussins calopsittes qu'il a exposés à des mélodies sifflées. Quelques mois après l'éclosion, trois de ces poussins imitaient ces mélodies : l'auteur suggère que ce serait dans le but d'attirer l'attention des humains. De

plus, certains oiseaux ont montré spontanément un rapide hochement de tête pendant la diffusion de musique humaine. La temporalité de ce comportement a été analysée afin d'évaluer sa synchronisation rythmique et a montré une certaine régularité.

Il est également important de souligner que la sensibilité auditive des calopsittes a été documentée et se situe entre 2000 et 5000 Hz (Okanoya & Dooling, 1987), c'est-à-dire qu'elle chevauche largement celle de l'homme, comprise entre 2000 et 4000 Hz (Heffner & Heffner, 2006).

b. Les corbeaux à gros becs

Les corbeaux à gros becs (voir Figure 4.) sont des corvidés de l'ordre des passereaux. Ils sont capables d'apprentissage vocal. Ces oiseaux sont originaires de l'Asie du Sud-Est, mesurent 46 à 59 centimètres et pèsent entre 450 et 1000 grammes. Ils sont grégaires. Ils vivent essentiellement dans des zones urbaines et se nourrissent notamment dans les décharges (Matsubara, 2003). Lorsqu'ils sont captifs, une dominance linéaire s'installe, déterminée par l'agressivité et le sexe (les mâles dominent les femelles), et maintenue par la mémoire des rencontres passées avec les autres individus (Izawa & Watanabe, 2008).

Une étude a montré que les corbeaux à gros bec avaient un niveau individuel de latéralité élevé lors des comportements nécessitant l'usage de leur patte (Matsubara, 2003).

D'autres études se sont intéressées à leur cognition.

Leur mémoire a par exemple été étudiée à plusieurs reprises. Ces oiseaux ont notamment montré des capacités de mémoire visuelle (Goto & Watanabe, 2009). Ils peuvent discriminer des stimuli colorés mais aussi, après un bref entraînement, mémoriser sur du long terme ces même stimuli colorés (Bogale et al. 2012). Plus encore, ils sont capables de méta-mémoire (Goto & Watanabe, 2012), la capacité consistant à gérer sa propre mémoire : ils peuvent évaluer la force de leurs souvenirs et adapter leur comportement en fonction.

Les études portant sur les capacités numériques des corbeaux à gros becs montrent que ces oiseaux ont tendance à sélectionner les quantités les plus larges de façon naturelle, et que leurs décisions sont affectées par le ratio numérique et l'ordre de grandeur des stimuli, ce qui indique une capacité de jugement numérique (Bogale et al., 2011a). Ils peuvent

également comparer des quantités, mais cette capacité semble disparaître quand l'indice du volume est retiré (Bogale et al., 2014).

Enfin, plusieurs études sur la cognition sociale des corbeaux à gros becs ont été effectuées. Ces oiseaux montrent des comportements exclusivement agressifs quand on leur présente un miroir (Kusayama et al., 2000), ce qui suggère qu'ils ne reconnaissent pas l'image comme étant la leur. Ils semblent en revanche être capables de reconnaissance individuelle (Izawa & Watanabe, 2008) : ils différencient les cris de leurs congénères et peuvent reconnaître des membres de leur groupe via des modalités croisées (auditives et visuelles), mais pas des non-membres du groupe (Kondo et al, 2012). Les corbeaux à gros becs peuvent également catégoriser des photographies de visages humains en se basant sur des similarités perceptuelles, qui diffèrent en fonction des individus : c'est à partir de la couleur qu'ils semblent discriminer le plus facilement, mais certains oiseaux se baseraient aussi sur les contours du visage, entre autres informations visuelles (Bogale et al., 2011b).

Figure 4. Corbeau à gros bec,

Centre for Advanced Research on Logic and Sensibility (Japon)

Crédit Photo : Mathilde Le Covec

2. Sujets

a. Les calopsittes élégantes

Les calopsittes élégantes de ce travail de thèse sont hébergées au Laboratoire Ethologie Cognition Développement, à l'université Paris Nanterre. Pour les informations complémentaires concernant les oiseaux, voir Figure 5.

Les calopsittes sont hébergées selon les conditions standards approuvées par les autorités nationales françaises. Ce travail de doctorat est en accord avec la législation française et européenne concernant les animaux de laboratoire, et a été approuvé par le comité d'éthique pour l'expérimentation animale Charles Darwin (numéro d'autorisation : #7035 2016093011025283 v2).

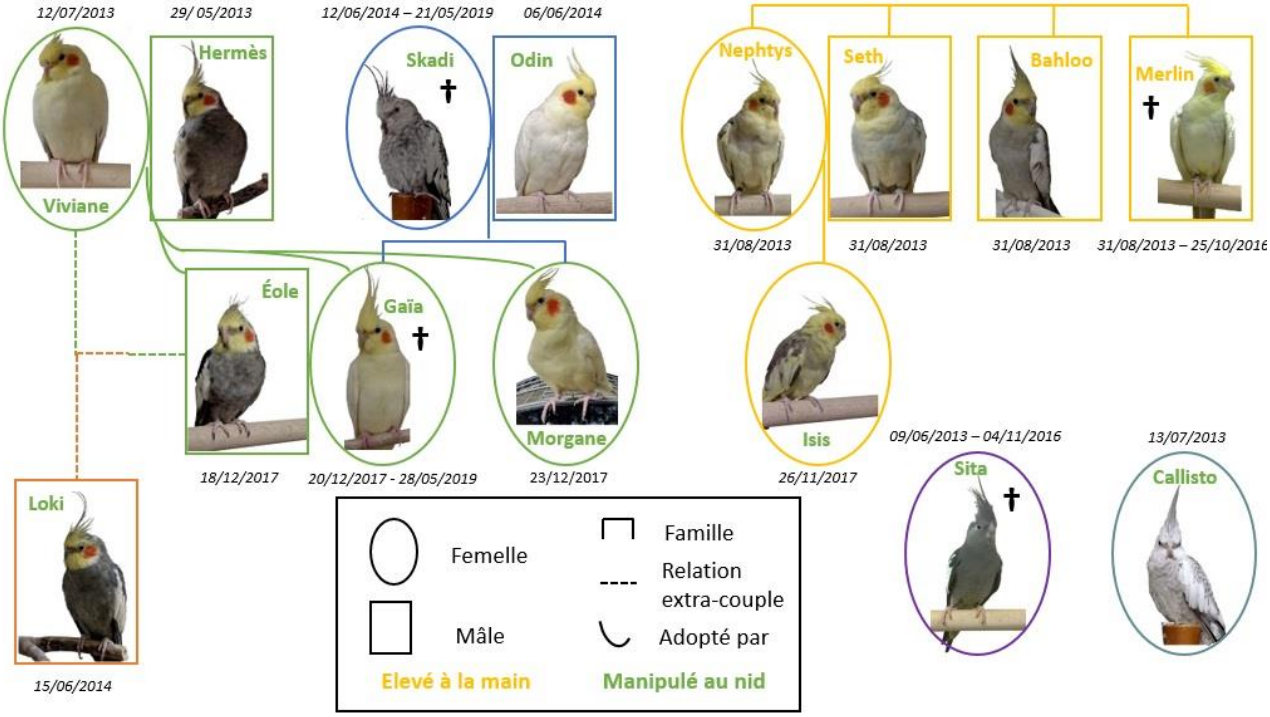


Figure 5. Trombinoscope des calopsittes du laboratoire (prénom, date de naissance et de mort si nécessaire, lien de parenté / couples et mode d'élevage)

Crédit : Mathilde Le Covec

b. Les corbeaux à gros becs

Ce doctorat a été effectué en collaboration avec le Pr Watanabe, du Centre for Advanced Research on Logic and Sensibility, qui dépend du département de psychologie de l'université de Keio (Japon). Les corbeaux à gros bec de ce travail de thèse y sont hébergés. Leur nombre est de huit (quatre femelles et quatre mâles). Tous les oiseaux ont été capturés dans leur première année de vie, dans Tokyo et ses environs. Ils étaient sevrés, capables de voler et indépendants de leurs parents, mais pas sexuellement matures. Par la suite, ils ont été hébergés au laboratoire dans des cages individuelles.

Les oiseaux ont été attrapés avec la permission du ministre de l'environnement du Japon (numéro d'autorisation : #2025575).

IV. Buts de la thèse

Malgré les quelques études ayant déjà exploré la musicalité chez l'animal non-humain, certaines zones d'ombre demeurent.

Premièrement, peu d'hypothèses portant sur les origines de la musique et de la musicalité ont été véritablement approfondies chez l'animal non-humain : l'hypothèse de la sélection sexuelle n'a jamais été abordée sous l'angle de la musicalité, celle du jeu comme précurseur de la musique n'a jamais été testée, et celle de la musicalité comme renforçateur des liens sociaux n'a été que peu étudiée. L'hypothèse de l'apprentissage vocal comme facilitateur de la musicalité commence à être explorée ; cependant aucune étude comparative avec l'être humain permettant de renforcer cette notion d'évolution convergente n'a encore été effectuée.

Deuxièmement, les définitions de la musique et de la musicalité sont souvent peu claires, voire pas du tout abordées dans ces études. À notre connaissance, aucune recherche ne s'est encore intéressée aux critères musicaux que pourraient remplir les animaux non-humains.

Enfin, si le modèle « psittaciforme » se révèle de plus en plus pertinent pour l'étude de la musique et de la musicalité chez les animaux non-humain, aucune recherche en ce sens n'a à

ce jour été publiée chez les corvidés, alors même que ces deux groupes d'oiseaux sont très souvent comparés sur le plan cognitif.

Ce travail de thèse vise, notamment et dans une certaine mesure, à éclaircir ces zones d'ombre et s'intéresse donc à la sensibilité musicale chez deux espèces d'oiseaux, les corbeaux à gros becs et les calopsittes élégantes. Nos objectifs sont les suivants.

(1) La musique étant souvent considérée comme une spécificité humaine, cette thématique, lorsqu'elle est abordée chez l'animal non-humain, soulève certaines questions plus philosophiques ; nous souhaitons donc étudier quels critères de musique et de musicalité remplissent les oiseaux.

(2) Déterminer si les animaux, et plus spécifiquement les oiseaux, sont influencés par la musique, peuvent montrer des préférences musicales, et produire des sons et des rythmes réguliers par l'intermédiaire de différents objets pourrait nous permettre d'en savoir plus sur l'évolution de la musique et de la musicalité ; nous souhaitons donc explorer les hypothèses la liant à l'apprentissage vocal, au jeu, à la sélection sexuelle et au renforcement des liens sociaux, ainsi que la notion de convergence évolutive éventuelle de ces comportements.

(3) Nous cherchons également à proposer certaines pistes d'enrichissement animal : si la musique a une influence positive sur les interactions sociales et qu'il existe des préférences individuelles, sa diffusion pourrait être un facteur de bien-être et permettre ainsi d'améliorer les conditions de vie d'animaux captifs (élevages, laboratoires, particuliers...).

Pour cela, nous étudierons chez les oiseaux l'aspect perceptif / sensitif de la musique et l'aspect production en interaction avec l'environnement selon trois axes majeurs : l'influence de la musique sur les comportements prosociaux et individuels (que nous mettrons en relation avec une étude similaire chez les enfants), les préférences musicales selon différentes modalités et l'expression sonore et rythmique.

Chapitre 1 : Influence de la musique sur les comportements individuels et les interactions sociales chez les calopsittes élégantes et les enfants

Parties 1 : chez les calopsittes élégantes, et 2 : chez les enfants

Dans ces deux études, nous avons comparé les comportements de 13 calopsittes aux comportements de 144 enfants exposés à de la musique consonante, dissonante ou pas de musique. L'étude portant sur les enfants a été conduite par le Dr Carla Aimé. Nous avons posé 3 hypothèses.

(1) En lien avec l'hypothèse de la musique comme renforçateur des liens sociaux, nous supposons que la musique aura un effet positif sur les comportements interactifs chez les oiseaux comme chez les enfants. Nous supposons également que la musique aura un effet positif sur leurs comportements individuels et qu'elle améliorera leur bien-être.

(2) La consonance étant souvent décrite comme agréable à l'oreille, par opposition à la dissonance, nous postulons que la musique consonante favorisera davantage que la musique dissonante le bien-être et les interactions positives, chez les oiseaux comme chez les enfants.

(3) Nous souhaitons également explorer l'hypothèse d'une évolution convergente concernant l'apprentissage vocal et la musicalité chez les humains et les calopsittes : les deux sont en effet capables d'apprentissage vocal. Des résultats comparables entre ces deux espèces permettraient de renforcer cette hypothèse, mais également de soutenir l'idée selon laquelle la musique serait aussi une adaptation biologique, et pas uniquement une invention culturelle.

Chapitre 2 : Préférences musicales chez les calopsittes élégantes et les corbeaux à gros becs selon différentes modalités

Partie 1 : Chez les calopsittes élégantes

Dans cette étude, nous avons proposé aux oiseaux un écran sur lequel étaient dessinées deux formes diffusant, au cours de trois tests successifs, deux types de musique différents. Nous avons posé les hypothèses suivantes.

(1) En lien avec l'hypothèse de l'apprentissage vocal comme facilitateur de la musicalité, nous supposons que les calopsittes, parce qu'elles sont capables d'apprentissage vocal, montreront des préférences musicales individuelles.

(2) Nous suggérons également qu'il y aura un lien entre les préférences musicales des oiseaux et leur personnalité.

(3) La consonance étant souvent décrite comme agréable à l'oreille, par opposition à la dissonance, nous postulons que les oiseaux montreront une préférence générale pour la consonance par rapport à la dissonance.

Partie 2 : Chez les corbeaux à gros bec

Dans cette étude, nous avons placé individuellement sept corbeaux dans une volière, devant laquelle étaient diffusés successivement dans la même journée cinq types de sons de quinze minutes, entrecoupés chacun de quinze minutes de silence. Nous avons posé deux hypothèses.

(1) Nous supposons que les corbeaux à gros becs seront capables de discriminer différents types de musique, et en conséquence montreront des différences comportementales en fonction de ce qu'ils entendent.

(2) En lien avec l'hypothèse de l'apprentissage vocal comme facilitateur de la musicalité, nous suggérons également que la musique aura un effet renforçateur sur les corbeaux à gros bec, qui montreront donc à son écoute plus de comportements positifs et moins de comportements de stéréotypies qu'en silence ou en bruit blanc. Nous supposons aussi que les corbeaux montreront des préférences musicales, et plus spécifiquement pour la musique japonaise, parce qu'ils vivent au Japon, qui est leur pays d'origine.

Chapitre 3 : Production sonore et rythmique chez les calopsittes élégantes et les corbeaux à gros becs

Partie 1 : Production sonore chez les calopsittes élégantes

Dans cette étude, nous avons fourni à treize calopsittes différents objets produisant des sons (xylophones, grelots, maracas…) ou n'en produisant pas. Nous avons posé trois hypothèses.

(1) En lien avec l'hypothèse du jeu comme précurseur de la musique et celle de l'apprentissage vocal comme facilitateur de la musicalité, nous supposons que les calopsittes joueront avec les objets et qu'elles produiront plus de manipulations sonores que de manipulations non sonores, selon des critères pouvant s'inscrire dans la définition de la musique.

(2) En lien avec l'hypothèse de la sélection sexuelle, nous suggérons que les mâles seront plus motivés que les femelles à produire des sons, spécialement lors de comportements de parades et pendant la période de reproduction.

(3) Nous postulons également que les jeunes oiseaux manipuleront et interagiront plus avec les objets que les adultes : les comportements exploratoires sont fréquemment observés chez les juvéniles.

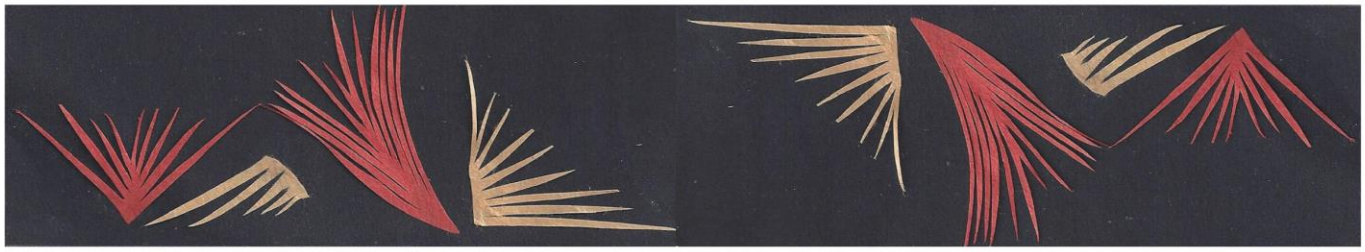
Partie 2 : Production rythmique chez les perruches calopsittes et les corbeaux à gros becs

Dans cette étude, nous avons relevé tous les comportements de tambourinages spontanés avec le bec observés dans les différentes vidéos réalisées pour les besoins de cette thèse. Nous avons posé trois hypothèses.

(1) Nous supposons que les tambourinages spontanés des individus montreront des intervalles suffisamment réguliers pour être qualifiés de tempos et être considérés comme une expression motrice du tempo moteur.

(2) Nous nous attendons à ce que les tambourinages moteurs spontanés diffèrent entre deux individus d'une même espèce, comme c'est le cas chez les êtres humains.

(3) Nous suggérons que les tambourinages moteurs spontanés seront différents chez les calopsittes élégantes et les corbeaux à gros becs.



Chapitre I : Influence de la musique sur les comportements individuels et les interactions sociales chez les calopsittes élégantes et les enfants

1.1 Chez les calopsittes élégantes

Effects of listening to music on behaviour and social interactions in cockatiels (*Nymphicus hollandicus*)

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Acknowledgments

The authors would like to thank O. Bouillet, P. Groué and E. Martin for taking care of the birds.

Moreover, the authors would like to thank Stephan Koelsch, who made available for us the consonant and the dissonant musical stimuli used in this study, and Mathieu Amy for helpful advices regarding the statistical analyses.

Abstract

Music exists in all human cultures and may have evolved in order to promote group cohesion. Several non-human animals also seem to display a certain musicality. Among them most are vocal learners, such as songbirds and parrots, suggesting that vocal learning could be a prerequisite to musicality. In this study, we compared the behaviour of 13 cockatiels between three situations: exposition to consonant music, exposition to dissonant music and control (no music). We explored interactive and individual behaviour, using behavioural observations and a sharing task. The results showed a significant effect of hearing and type of music on interactive and individual behaviour. They suggest that the birds pay attention

to music and are able to distinguish consonance from dissonance, but also attest that music lowers aggressiveness and increases proximity, and thereby could promote positive social interactions and be a factor of welfare. Regarding the sharing task, we did not find any significant effect of the presence nor the type of music. Our findings support the idea that musical abilities could be a case of convergent evolution between species that are capable of vocal learning, and promote in those species positive social interactions and group cohesion.

Key words: evolution of music, musical influences, social interactions, prosociality, birds, psittaciformes, music discrimination

Introduction

According to Watanabe et al. (2009), given that most cultures have their own music, including people with a traditional lifestyle, music is likely to have a long history. Nevertheless, music is a complex concept, for which there is no consensus on the definition yet. The concept of musicality is broader and might be easier to explore. Musicality has been described by Hoeschele et al. (2015) as "the capacity that makes it possible for us to perceive, appreciate and produce music".

Why did music emerge in humans?

For Freeman (1998), music and dance could have evolved biologically and culturally as a way to strengthen social bonds and form societies. Indeed, music has been shown to impact group cohesion: songs sharing social functions have convergent forms across cultures (Mehr et al. 2018), they can strengthen the solidarity of groups, like soldier songs (Cleveland, 1985) and trigger ethical behaviour, as is the case of religious songs among religious people (Lang et al. 2016). Listening to music in families and peer groups also contributes to group cohesion (Boer and Abubakar 2014) and social intentions can be communicated through musical interaction in expert improvisers (Aucouturier and Cannone 2017). Finally, some studies show that, in children, playing music together enhances prosocial behaviour (Kirschner and Tomasello 2010) and empathy (Rabinowitch et al. 2012).

What about other animals?

It has been shown that, although music has been made by and for humans, it can also influence emotions in some non-human animals: in rats, it triggers an increase in calcium / CaM-dependant dopamine synthesis in the brain, suggesting that it could lower symptoms in diseases involving dopamine dysfunction (Sutoo and Akiyama 2004), and beneficial physiological changes occur in response to music in dogs, implying that it could lower their stress level (Bowman et al. 2017). Therefore, it seems that several abilities that are necessary for music perception also exist in some non-human species. However, little is known about musicality in non-human animals and how it may have evolved.

Musicality in non-human primates

Because they are phylogenetically very close to us, studying apes and monkeys is logical when we want to understand how a specific feature has appeared and evolved in mankind. However, such studies show contrasted results. Indeed, only a few chimpanzees show musical preferences (Mingle et al. 2014; Sugimoto et al. 2010), Sumatra orangutans do not show any discrimination or preferences (Ritvo and McDonald 2016) and marmosets and tamarins prefer slow tempi over fast ones, but prefer silence to music (McDermott and Hauser 2007). As for rhythm, in Hattori et al. study (2013), only one chimpanzee out of three was able to synchronize her tapping with the sound she heard, after a very long training. Drumming has been shown in several male chimpanzees (Babiszewska et al. 2015) and in a captive one, Barney, whose performance followed the structural and contextual features we can find in human musical drumming (Dufour et al. 2015). Yet a complementary study to Barney's case found no other rhythmical episodes that could meet the criteria of musical production in other individuals (Dufour et al. 2017). Thus, the number of examples of non-human primates interested in music remains small, and tends to show that apes and monkeys may not be the best models to study the evolution of musicality.

The vocal learning hypothesis

These limited musical abilities in non-human primates could be related to their restricted abilities for vocal learning.

Indeed, as well as non-human primates, other species with low vocal learning abilities, such as pigeons (Watanabe et al. 2009) or hens (McAdie et al. 1993) show no clear musical preferences. Therefore, according to Watanabe et al. (2009), an animal would not show musical preferences if it is not capable of vocal learning: musical stimuli would be reinforcing only in species that learn complex auditory stimulations during their ontogeny. Patel et al. (2008) also suggest that vocal learning is a prerequisite to rhythm entrainment. Indeed in mankind, a coupling between motor and vocal development appears as early as 12 to 15 weeks of gestation (de Vries et al. 1985), infants vocal-motor coordination enables the development of gesture speech in adults (Iverson 2010) and in general, auditory pathway

connections between auditory regions and motor planning regions would be stronger in humans than in non-human primates, because they are capable of vocal learning (Patel and Iversen 2014).

Yet among animal species only a few are able to learn vocal stimuli, like songbirds and parrots, which learn to produce songs or other vocal signals during their ontogeny (Fitch 2006). Thus, birds that are capable of vocal learning could be better candidates than non-human primates when we want to study and understand the development and evolution of music.

Musicality in birds

Several composers, such as Mozart, Beethoven or Messiaen, created musical plays inspired by the song of birds. Indeed, birdsong and music share several specificities, as it has been shown in various studies: many birdsongs sing according to precise rules, some of them being probably similar to those inducing emotions when we listen to human music (Rothenberg et al. 2014). Doolittle et al. study (2014) demonstrated that the hermit thrush song displayed the same mathematical principles than those underlying western and non-western musical scales, showing a convergence between human and animal "song cultures".

Among vocal learners, some Java sparrows show a consistent preference for Bach compared to Schoenberg and for Vivaldi compared to Carter: they prefer classical music over modern music (Watanabe and Nemoto 1998), yet these preferences vary among individuals. African grey parrots can use a touch screen allowing them to choose to listen to different kinds of music, and show individual preferences, which seems to be influenced by personality (Péron et al. 2012). Bullfinches, known for learning melodies from human teachers, are able to whistle a human song melody taught by auditory feedback, but also to anticipate synchronously the consecutive part of the learned melody (Nicolai et al. 2013) and Theo, a grey parrot, was able to sing in response to a musical stimulus and to generalize the musical rules she heard to other notes (Bottoni et al. 2003). Theo's musical sequences were so complex and innovating that the authors explained it could not be just imitation. As for the ability to entrain to a rhythm, it has also been demonstrated in vocal learners like parrots (Patel et al. 2009): six species of them at least have been observed spontaneously entraining to a rhythm (Schachner et al. 2009); palm cockatoos can even create tools with

which they perform regular beat productions and repeated components in a consistent context with individual styles, sharing key rudiments of human instrumental music (Heinsohn et al. 2017).

Therefore, it appears that humans and birds share some features of musicality. As mentioned before, those features seem more limited in non-human primates, in spite of their phylogenetic closeness with humans. Thus it is unlikely that musicality is an ancestral trait that would have evolved in a common ancestor to humans and birds; conversely, musicality could have evolved independently twice, both in humans and birds, as a case of convergent evolution facilitated by vocal learning abilities. In humans, it has been suggested that musicality could have evolved because it improves group cohesion; indeed Hagen and Bryant (2003) suggest that music signals the existence of a coalition and its quality. In birds, song-duetting improves the reinforcement of the pairbond by allowing mate-guarding, joint territorial advertisement and synchronization of breeding (Sonnenschein and Reyer 1983). More specifically, in parrots, duets allow a joint-territory defense (for example in yellow-naped amazons: Dahlin and Whright 2012), vocal matching enables to interact with all individuals of a population, without being constrained to understand only a part of this population (Balsby and Bradbury 2009) and dancing with a rhythm could be related to social actions (Fitch 2009). Those suggestions and hypotheses bring the subject of the influence of music on group cohesion and prosociality.

Prosociality in birds

One way to study prosociality in animals is food-sharing.

Food sharing is an altruistic behaviour, given that it costs to the donor and benefits to the receiver. It has been studied in various species and more specifically in birds like cliff swallows (Brown et al. 1991) and long-tailed tits (Nam et al. 2010). It is broadly documented in corvids: feeding cooperative behaviour has been discovered in Carrion crows in Northern Spain (Baglione et al. 2002) and young common ravens communicate the food location of carcasses to their conspecifics (Heinrich and Marzluff 1995). In some species, it contributes to social bonds, especially in pair mates, as is the case in rooks (Clayton and Emery 2007) and

jackdaws (von Bayern 2007). In cockatiels, a psittacid species, it is influenced by affinity and kinship (Liévin-Bazin et al. 2019).

To our knowledge, the influence of music on prosociality has not been studied in birds yet.

The current study

This study aims to compare individual behaviour and interactive behaviour in 13 cockatiels between three situations: exposition to consonant music, exposition to dissonant music and control (no music). Cockatiels belong to the psittaciforme order, in which birds share complex cognitive skills with primates and are capable of vocal learning. As mentioned before, psittaciformes seem to share some features of musicality with humans (*e. g.* cockatoos are able to entrain to a rhythm, Patel et al. 2009); as numerous videos show it as well on the Internet, they whistle, dance, sing and entrain to a rhythm. Furthermore, cockatiels are easy to host and very sociable.

First, we attempt to explore the relationship between hearing music and interactive behaviour. Indeed, in humans, music may have evolved because it promotes interactions, prosociality and social bonding (Freeman 1998). Musicality might also have evolved in birds thanks to a similar effect. In this case, we expect that the birds would be more prosocial and interact more positively when hearing music compared to control. We also aim to test the influence of music on individual behaviour: indeed, music has been shown to alter behaviour in birds (Robbins and Margulis 2016).

Second, we intend to explore whether music may have emerged in humans and cockatiels by convergent evolution (*i.e*. independently but with the same adaptive function, in this case promoting social interactions), given that both are capable of vocal learning and, as mentioned before, promising results have already been observed in vocal learners.

Finally, we wish to test for the role of consonance as an important musical feature involved in this relationship. In their most simple definition, consonant intervals are those

that sound smooth or pleasant, while dissonant intervals are those that sound rough or unpleasant (Trainor and Heinmiller 1998). Infants, like adults, have a preference for consonance over dissonance, suggesting that in musical processing, the consonance / dissonance feature is very basic (Trainor and Heinmiller 1998). In non-human animals, consonance and dissonance trigger different neural responses in the auditory nerve (Tramo and al. 2001) and the inferior colliculus (McKinney et al. 2001) in cats, and in the primary auditory cortex in monkeys (Fishman et al. 2001). Chicks (Chiandetti and Vallortigara 2011) prefer to approach an object associated with consonant melodies over dissonant melodies and an infant chimpanzee preferred consonant melodies over dissonant melodies (Sugimoto et al. 2010). Thus, it seems that the preference for consonance over dissonance is not unique to humans. Therefore we assume that consonant music would promote welfare and trigger positive interactions between birds more than dissonant music.

Materials and methods

Subjects and housing conditions

This experiment was held in the Laboratoire Ethologie Cognition Developpement (LECD) in Nanterre University (France), with thirteen cockatiels (*Nymphicus hollandicus)* (see Table 1). The birds were housed in an indoor aviary (296x257x257 cm) with no window. The temperature was 23°C and the light was on from 9 am to 11 pm. Three stainless steel work benches (155*55*84 cm) were located on the left wall and there were two big perches in the middle of the room. Toys, cardboards and two triangle suspended perches were also available. Birds were feed ad libitum with seed Deli Nature for large parakeets, various fruits and vegetables (but not fennel, a preferred food used during the experiment), aniseed sand and water. Birds were deprived of food two hours before the beginning of each session.

Table 1. Name, sex and age of the birds

Name	Sex	Age when the experiment began
Hermès	Male	3 years 10 months
Callisto	Female	3 years 8 months
Viviane	Female	3 years 8 months
Nephtys	Female	3 years 7 months
Seth	Male	3 years 7 months
Bahloo	Male	3 years 7 months
Skadi	Female	2 years 11 months
Odin	Male	2 years 11 months
Loki	Male	2 years 11 months
Isis	Female	4 months
Eole	Male	4 months
Gaïa	Female	4 months
Morgane	Female	4 months

Stimuli

Consonant and dissonant music stimuli were taken from Koelsch et al. study (2006). Consonant stimuli were ten excerpts instrumental dance-tunes (all major-minor tonal music) (see table 2). To create the dissonant stimuli, the original tunes were electronically manipulated (using CoolEdit Pro software, by Koelsch et al., 2006), *i. e.* recorded simultaneously with two pitch-shifted versions, which were one tone above and a tritone below the original pitch.

Table 2: Running order, time, composers and names of the plays included in the stimuli

Running order	Time	Composer and name of the play
1	00 – 00:56	Anonymous, Entree-Courante
2	00:56 – 01:55	J.S. Bach, Badinerie (Overture No. 2, BWV 1067)
3	01:55 – 02:38	J.S. Bach, Bourrée (Overture No. 1)
4	02:38 – 03:38	P. Castellanos, La Puñalada
5	03:38 – 04:29	P.F. Caroubel, Volte
6	04:29 – 05:27	A. Dvorák, Slavonic Dance No. 8 in G Minor (Op. 46)
7	05:27 – 06:20	A. Dvorák, Slavonic Dance No. 1 in B Major (Op.72)
8	06:20 – 07:07	V. Haussmann, Catkanei
9	07:07 – 08:07	Pee Wee Ellis, Soul intro ("The Chicken")
10	08:07 – 09:05	J.S. Bach, Réjouissance (BWV 1069)

Study design

First of all, in order to familiarize the birds with music, we broadcasted to them classical music, different from the two stimuli described above, for one hour a day (twice in the morning and three times in the afternoon).

The experiment sessions began five days later. All testing was done in the aviary and was filmed. The camera was stationary for the first seven minutes and held by one experimenter during the prosocial test (the birds tending to move, we needed to follow them through the aviary). Three experimenters familiarized with the birds were present: the first one filmed, the second one fed the bird involved and the third one checked that the other birds would not disturb the experiment (*e. g.* chewing the wire equipment, etc…). The birds were tested in three conditions: consonant music, dissonant music (using the two stimuli described above) and control (no music), in eighteen experimental sessions (six per condition) over four months. The sessions were composed of two phases – (1) broadcast only and (2) broadcast and prosocial test. Music was broadcasted with a Bluetooth speaker with constant volume (55-65 dB). After seven minutes, four or five birds per session were tested on their prosocial behaviour (note that the music was still going on and that the tested birds were not isolated from the other birds, but they were the only ones who received food from us during this session). During the prosocial test, each tested bird received ten pieces of fennel.

Most of the time, one given bird received successively ten pieces of fennel before we proceeded to another bird. We waited for each piece to be eaten, fallen to the ground or refused before giving the next one. Once all the ten pieces of food were eaten, fallen on the ground or refused, the following bird also received ten pieces of fennel, until all the birds of the tested group had received the fennel. If at one time a bird refused the food several times, we fed another bird and then came back to the previous one, and so on until every bird of the group was presented ten pieces of fennel. Each session lasted on average between 15:00 and 25:00 minutes (the variability is due to the fact that the eating time varies according to the birds).

The groups of tested birds remained the same during all testing sessions (*e.g.* the group A included Nephtys, Skadi, Loki and Eole, etc.). The birds' running order within a group was randomized and the groups' running order, conditions and moments of the day were counterbalanced.

Coding

All videos were coded using a preestablished template.

The videos were divided between the three experimenters to be analyzed.

We recorded the birds' interactive and individual behaviour observed during broadcast only, as described in table 3. We also recorded the birds feeding strategies observed during broadcast and prosocial test, as described in table 4.

Table 3. Recorded behaviour during broadcast only

Interactive behaviour	
Proximity (duration)	Two birds staying close to each other, *i. e.* close enough to peck each other, for at least 3 seconds
Allopreening (occurrences)	Two birds preening one another
Preening request (occurrences)	A bird requesting another bird to preen, *i. e.* him / her lowering his / her head or taking another bird's leg in his / her beak
Agonistic behaviour (occurrences)	A bird pecking another bird with or without contact, opening his / her beak to threaten another one
Individual behaviour	
Moving behaviour (occurrences)	Bird moving (*i. e.* walking) for 3 seconds or more
Take-off (occurrences)	Bird taking off

Table 4. Recorded behaviour during broadcast and prosocial test

Shared piece (occurrences)	Bird sharing the piece of fennel with another bird
Theft (occurrences)	Bird to whom another bird is taking the peace of fennel, with at least one of the two being aggressive toward the other
Consumption (occurrences)	Bird eating the piece of fennel alone
Dropped piece (occurrences)	Bird dropping the piece of fennel
Refusal (occurrences)	Bird taking off without accepting the piece of fennel (after 10 refusals, the bird was given no more fennel)

Statistical analysis

First, we tested whether the conditions (consonant music, dissonant music and control) influence interactive behaviour (spatial proximity, allopreenings, preening requests, agonistic behaviour) and individual behaviours (moving behaviour, take-offs, chewings, self-preenings, songs, stillness and relaxed behaviour) during broadcast only. Then, we tested whether the conditions influence the feeding strategies (number of shared pieces, thefts, consumptions, dropped pieces and refusals) during phase broadcast and prosocial test. Each dependent variable was analyzed in a distinct generalized linear mixed model (GLMM), using the R program v3.4.3 (R Core Team 2017) and the add-on package lme4 (Bates et al. 2015). We included conditions and times of the day (morning or afternoon) in the model as fixed effects, and the identity of the bird (or the dyad when the dependent variable was an interactive behaviour) as a random effect. In addition, regarding the behaviour recorded during broadcast and prosocial test, as the ten pieces of fennel were given to each bird individually, we also included the running order as a fixed effect. We used a gamma distribution for spatial proximity (since this variable was expressed as a duration), and a Poisson distribution for the other variables (expressed as counts). Finally, to maximize the model likelihood and to eliminate any unnecessary fixed effects, we used a backward stepwise approach: we started with all the fixed terms cited above, tested deletion of each one, deleted this term if deletion improved the model's likelihood, and repeated the process until no further improvement was possible. We used LRT tests implemented in the "Anova" R function to test for significant improvement of the model's likelihood and to obtain p-values for fixed effects. In addition, we used post-hoc Tukey tests (Tukey 1949) to perform pairwise comparisons between conditions.

Results

Broadcast only – interactive behaviour

As shown in **Table 5**, presence and type of music have significant effects on proximity, agonistic behaviour, allopreenings and preening requests. In particular, post-hoc Tukey tests show that the birds stayed closer to each other but did less preening requests when hearing consonant music compared to dissonant music or control. They also did less allopreenings when hearing consonant music compared to dissonant music, and they tended to do less allopreenings when hearing consonant music compared to control. The birds were also less agonistic when hearing music (consonant or dissonant) compared to control.

Table 5. GLMM analyses of spontaneous behaviours during the music influence experiment (broadcast only)

dependent variable	Fixed effects (final model)	χ2 (LRT test)	DF	p (LRT test)	Consonant vs control	dissonant vs control	consonant vs dissonant
proximity	music	18,13	2	**0,0001**	**<0.001**	0,54	**0,01**
agonistic behaviors	music	72,01	2	**2.3x10-16**	**<0.001**	**<0.001**	0,51
	daytime	11,26	1	**0,0008**	_	_	_
allopreening	music	13,912	2	**0,001**	0,07	0,3	**0,001**
	daytime	10,87	1	**0,001**	_	_	_
preening requests	music	31,3	2	**1.5x10-7**	**0,003**	0,33	**<0.001**
	daytime	6,11	1	**0,01**	_	_	_
Moving	music	15,7	2	**0,0003**	**0,005**	**0,002**	0,95
preening	music	30,5	2	**2.4x10-7**	**<0.001**	**0,02**	**0,01**
chewing	music	26,25	2	**2.0x10-6**	**<0.001**	**<0.001**	**<0.001**
flying	music	12,39	2	**0,002**	0,05	0,06	0,83
immobility	music	10,44	2	**0,005**	**0,006**	**0,03**	**0,84**
inactivity	music	14,42	2	**0,0007**	0,001	0,93	0,005

Broadcast only – individual behaviour

As also shown in **Table 5**, presence and type of music have also significant effects on individual behaviour. In particular, post-hoc Tukey tests show that the birds moved less, self-preened less, chewed less and tended to fly less when hearing either consonant or dissonant music compared to control. They also self-preened less and chewed less when hearing consonant music compared to dissonant music. Type of music (*i.e.* consonant or dissonant) had no significant effect on moving behaviour and take-offs. In addition, the birds were stiller or more relaxed when hearing music compared to control. Finally, they sang more when hearing dissonant music compared to consonant music or control.

Table 6. GLMM analyses of spontaneous behaviours during the music influence experiment (prosocial test)

Behaviour	Fixed effects (final model)	χ2 (LRT test)	DF	p (LRT test)
sharing	none	_	_	_
stealing	daytime	4,3	1	**0,04**
consumming	passation order	25,27	1	**3.3x10-6**
dropping	passation order	27,48	1	**1.1x10-6**
refusing	none	_	_	_

Prosocial test

As shown in **Table 6**, there were no significant differences between conditions regarding feeding strategies (shared pieces, thefts, consumptions, dropped pieces or refusals). Indeed, for these dependent variables, including condition as a fixed effect in the GLMM models did not lead to a significant increase in the model likelihood.

Discussion

The aim of this study was to compare the behaviour of 13 cockatiels between three situations: exposition to consonant music, exposition to dissonant music and control (no music). We found some significant effects of hearing and type of music on interactive and individual behaviour. Our findings suggest that the birds pay attention to music and are able to distinguish consonance from dissonance. The results also support the hypothesis according to which music lowers aggressiveness and thereby could promote positive social interactions and be a factor of welfare. Regarding the sharing task, we did not find any significant effect of the presence nor the type of music.

Do birds pay attention to music?

Our birds have less maintenance behaviour (moving behaviour and take-offs tendencies), they chew less and are stiller and more relaxed when hearing music compared to control. Another study showed that hens preen less when hearing country, jazz or classical music (Ladd et al. 1992). Besides, on psittacines, pop music decreases the number of calm vocalizations (Williams 2017).

This could suggest that the birds pay more attention to music, and thus tend to stop their usual activities.

Hearing music promotes interactive behavior

Our results are concordant with some other studies in humans and non-human animals.

In human beings, some studies suggest an influence of music on social behaviour: music therapy (in which music is listened to or played, according to the studies), improves the mood of patients (Guétin et al. 2009) but also reduces aggressiveness in aggressive children (Choi et al. 2008) and high school students (Geravand and Nuorifard 2014). This positive influence has also been demonstrated in non-human animals, such as laboratory chimpanzees (Videan et al. 2007), for whom instrumental music increases affiliative behaviour and vocal music decreases agonistic behaviour. Zoo-housed western lowland

gorillas (Wells et al. 2006), also tend to show less abnormal behaviour and conspecific-directed aggression when listening to classical music. Other studies explore the mechanisms involved in this relationship: several beneficial physiological changes occur in response to music in rats (Sutoo and Akiyama 2004) and dogs (Bowman et al. 2017).

Therefore, our results support the idea that music increases closeness between individuals and reduces aggressiveness.

The role of consonance

The fact that the birds have less allopreenings and less preening requests, that they self-preen less and chew less when hearing consonant music compared to dissonant music and control could be due to the fact that they pay more attention to consonant music than to dissonant music and thus tend to stop their usual activities. The ability to discriminate consonance from dissonance appears very early in human infants (it already exists in two days-old infants, Masataka 1999). Even though some animal species seem quite indifferent toward the consonance / dissonance feature, as is the case of rats (Crespo-Bojorque and Toro 2015), which are able to discriminate consonant and dissonant chords but not to generalize this discrimination to novel items, or cotton-top tamarins (McDermott and Hauser 2004) and Campbell's monkeys (Koda et al. 2013), which do not prefer a loudspeaker broadcasting consonant music over dissonant music, other studies demonstrate that the consonance / dissonance feature is not unique to humans. For example Java sparrows (Watanabe et al. 2005) and Japanese monkeys (Izumi 2000) can discriminate consonant chords and dissonant chords and even transfer this discrimination to novel frequencies of sounds. This ability to distinguish consonance from dissonance could thereby be innate, since it exists in several species. Bowling and Purves (2015) suggest that a biological sense of consonance would develop in any species generating harmonics in its vocal communication. As it happens, in parrots, contact calls consist in several harmonic series (Balsby et al. 2012). Whether the cockatiels prefer consonance over dissonance remains to be explored: a study aiming at answering this question is currently in progress.

Song

Interestingly, the results show that the birds sing significantly more when hearing dissonant music compared to consonant music or control. Actually, most of the songs were produced by one young male bird, Éole. In many songbirds, for example in nightingales, males overlap the song of opponent birds, in order to repel their territory (Hulsch et Todt. 1982; Kunc et al. 2006). Although parrots do not defend an all-purpose territory for breeding, they defend vocally the immediate area around their nest sites (Bradbury and Balsby 2016). We also have some empirical evidence that in captivity, various species of songbirds and parrots vocalize more when they hear various sounds (*e. g.* vacuum cleaner, running water, television or radio) than in silence. This behaviour is observed even in non territorial birds, such as weaver birds (Geberzahn, Le Covec and Bovet, unpublished observations). This behaviour is difficult to interpret, as it seems counterintuitive (most published studies focus on how birds adapt to environmental noise by reducing masking effects, for example by vocalizing more when levels of noise are low: Brumm and Zollinger 2013). Therefore Éole may sing more when hearing dissonant music because he dislikes it (and tries to mask it or to make it stop), but we cannot exclude that he prefers dissonant music, as we also observed psittacidaes vocalizing or singing along music or noise that they seem to appreciate.

Hearing music does not influence sharing behaviour

Regarding the presence or type of music, the results showed no significant differences between feeding strategies. This could be due to the experimental situation. Indeed, significant results were observed for the non-triggered and spontaneous behaviour, whereas the sharing task was induced and not spontaneous in this experiment. It was the experimenter who decided when each bird was going to be fed and the amount of fennel he / she was given.

Furthermore, these negative results could be due to the stimuli chosen. Indeed, each stimulus consisted of ten short musical excerpts from very different styles (classic, tango, jazz…). In consequence, during the diffusion of the music, many features like rhythm, melodies, instruments, etc… varied a lot and could also have triggered changes in the birds'

behaviour. Therefore, those variations within each stimulus may have limited the saliency of the consonance / dissonance feature.

It is also important to note that the sharing events were very scarce (only a total of 23). The fact that the birds did not share much in general could be due to their age: in jackdaws, food-sharing peaks while they are still developing and decreases by the time they have formed a bond with one affiliative partner (von Bayern 2007). Likewise, in cockatiels, food-sharing decreases during the first year of life and is mostly observed between related individuals or birds with affinities (Liévin et al. 2019). Indeed, among our cockatiels, most of sharing events occurred between young birds and / or siblings. Thus, the lack of significant difference regarding the sharing behaviour between the conditions could be a consequence of the scarcity of this behaviour.

The sensitivity to music, a case of convergent evolution?

Our study shows that music influences positively social interactions in cockatiels, as is the case in human beings (as mentioned above). This could suggest, as proposed by Freeman (1998) that musical abilities would have evolved so as to promote social bonds and group cohesion. Cockatiels being vocal learners, these results also support Watanabe et al. hypothesis (2009), which suggests that musical stimuli are only reinforcing in species that are capable of vocal learning. Indeed, other vocal learners like elephants show less stereotypies in zoo when exposed to classical music compared to silence (Wells and Irwin 2008), whereas in some non-vocal learners, there is no reinforcing effect of music, as is the case for pigeons (Watanabe et al. 2009); classical music even increases hens' fearfulness (Campo et al. 2005) and rock and classical music gorillas stereotypies (Robbins and Margulis 2014). Yet this hypothesis needs to be taken carefully into account: as said previously, music can have positive effects in some non-vocal learner species such as apes or rats; moreover, in captive dogs, classical music reduces stress level (Kogan et al. 2012) and barking and increases the time spent resting (Wells et al. 2002). Harp therapy also decreases captive dogs’ respiration rate, restlesssness and anxiety (Boone and Quelch 2003).

Both receptivity to music and vocal learning seem to be features shared by quite distantly related species (human beings and cockatiels): this could be a case of convergent evolution, that is to say that those traits would have evolved independently in two species but with the same adaptive function.

Another interesting aspect is the fact that consonance seems to be an important property of music for several species: in addition to humans (Trainor and Heinmiller 1998), chicks (Chiandetti and Vallortigara 2011) and one chimpanzee (Sugimoto et al. 2010) prefer consonance over dissonance, and our cockatiels display significantly different behaviour depending on the type of music they listen to (consonant or dissonant). This could support the hypothesis according to which one musical feature, the discrimination between consonance and dissonance, would not be unique to humans (Sugimoto et al. 2010).

Since the birds are closer to each other when hearing consonant music whereas they display a more agonistic behaviour in the control condition, music could also be a factor of welfare and enrichment for them. Whether this factor could be broadened to other species remains to be studied, yet it could have positive implications for some captive animals, in particular vocal learners.

Ethical statement

National guidelines for the care and use of animals were followed: the birds were housed according to standard conditions approved by the French National authorities.

All procedures were in accordance with the ethical standards of the institution or practice at which the studies were conducted. This study is in line with French and European legislation for animal care and was approved by the Ethical Committee for Animal Experimentation Charles Darwin (authorization number #7035 2016093011025283 v2).

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1.2. Chez les enfants

Is music an evolutionary adaptation?
Effects of listening to music on social interactions in preschool children.

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Acknowledgments

Carla Aimé has received a postdoctoral grant from COMUE Université Paris Lumières for this work. Moreover, the authors would like to thank Stephan Koelsch who made available for us the consonant and the dissonant musical stimuli used in this study. We also thank Damien Colace for video coding and Mathieu Amy for helpful advices regarding the statistical analyses. Finally, we warmly thank all participants, their parents, teachers, and school institutions.

Abstract

Music exists in all human cultures, suggesting that musical abilities may have spread in response to evolutionary pressures. In particular, music may promote group cohesion. This view is supported by some developmental studies showing that joint music making promotes prosociality in children. However, knowledge on the influence of listening to music on social behavior is scarce. Moreover, almost nothing is known about how the social effects of music vary across development, and which musical properties are involved. Here, we played back either consonant or dissonant music or a record of class sound (control) to 144 children from age 3 to 6. We compared prosocial behavior and social interactions among conditions using three tasks (sharing, cooperating and helping). The results showed that children listening to consonant music took more time to complete the sharing task because

they hesitated more when sharing the resources than children in the dissonant or control conditions, although the amount of shared resources between partners did not differ among conditions. Moreover, we found significant positive effects of listening to music on social interactions during the cooperation task (*i.e*. on mutual looks from age 3 to 5 and on verbal interactions from age 5 to 6). Consonant and dissonant music had similar effects before age 4, whereas only consonant music promoted social interactions in older children. To our knowledge, this study is first to demonstrate that listening to music, especially consonant music, promotes positive social interactions in children, and first to show that the sensitivity to consonance increases with age.

Key words: Evolution of music perception, musical influences, social interaction, prosociality, preschool children, development

Introduction

Music is a deeply social activity inducing emotional and behavioral responses (Trainor and Schmidt 2003; Juslin and Vastfjall 2008). It exists in humans for at least 40,000 years, as evidenced by the discovering of the Hole Fels flute - the oldest known musical instrument - in Germany in 2008 (Conard et al. 2009). Some forms of music exist in every human culture (Merriam 1964) and, although musical forms and meaning vary widely around the world, human musicality has some universal components (Brown 2013). In particular, music perception and production require some cognitive abilities that are widely shared among humans. Some of them, like melody recognition (Chang and Trehub 1977), perception of pitch and temporal patterns (Hannon and Trehub 2005, Trehub and Hannon 2006), and preference for consonant music (Trainor et al. 1998; Masataka 2006) have been observed even in very young infants, suggesting innateness. For instance, Masataka (2006) found a preference for consonance rather than dissonance in two-days-old infants, including in newborns of deaf parents. Trainor et al. (1998) obtained similar results with 2- to 4- months-old babies. These observations revive the debate of how musicality (*i.e*. the abilities that makes it possible to perceive and produce music, Hoeschele et al. 2015) emerged and spread so widely in humans' history.

The question of whether music was a cultural invention or an evolutionary adaptation has long been debated. Evolutionary theory (Darwin 1859) predicts that traits that are heritable (*i.e.* genetically or culturally transmitted to offspring) and adaptive (*i.e.* advantageous for survival and/or reproduction) in a given environment will tend to increase in frequency generation after generation in this environment, as they are transmitted to more offspring. Darwinian evolution may thus explain the wide spread of musical abilities among humans, provided that they are heritable and that a positive association exists between musical abilities and survival and/or reproduction. Heritability is supported by genome-wide linkage and association studies, which have identified some genetic variants associated with musical abilities (Ukkola et al. 2009, 2013). However, the existence and nature of any relationship between musical abilities and Darwinian fitness (*i.e.* survival and/or reproduction) are still open to question.

Answering these questions would have multiple outcomes. Indeed, beyond a better understanding of the origins of human musicality, identifying any adaptive function related

to musical abilities will help to understand how music can influence human behavior. This study is thus at a crossroad between evolutionary sciences and developmental psychology: by investigating the effects of listening to music on prosociality and social interactions in preschool children, we aimed at (1) investigating how listening to music influences human social behavior, (2) exploring how these effects vary across development, (3) identifying some musical properties involved, and (4) reaching a better understanding of how musical abilities evolved in humans.

How did musicality emerge in humans?

First, it is worth to mention that, according to some researchers, music might be a purely cultural invention, lacking any biological function. For instance, Pinker (1997) speculated that music had been invented as a pleasure activity, that it had no particular effect on survival and reproduction, and that all components of human musicality pre-existed and were involved in other functions like language or emotional communication. This hypothesis is commonly referred as the "Pinker's cheesecake hypothesis", by analogy with the popular dessert: whereas food is necessary for survival, the cheesecake recipe itself is a cultural invention with no particular function. However, this hypothesis does not provide any explanation for the worldwide spread of music in human populations. Indeed, as mentioned before, music is traditionally found in every culture (Merriam 1964). Furthermore, music has multiple documented effects on humans' emotions, on behavior, and even on cognitive performances. For instance, joint music making promotes empathy in 8 to 11 years-old children (Rabinowitch et al. 2012) and prosociality in 4 years-old children (Kirschner and Tomasello 2010). Music training may also promote mental and social development and play a beneficial role in cognitive functions. Indeed, an increasing number of studies show positive associations between music training in childhood and abilities in a variety of domains, including speech perception, reading, vocabulary, spelling, second-language acquisition, visuo-spatial abilities, memory, executive functioning, intelligence, and academic achievement (*e.g*. Schellenberg 2006; Hallam 2010). Human musicality may thus be a much more promising candidate as an evolutionary adaptation than cheesecakes, although experimental evidence is still needed to conclude.

Among the functional hypotheses for the origins of musicality as an evolutionary adaptation, two of them have been subjects of particular attention in the litterature: the "sexual selection hypothesis", and the "group cohesion hypothesis". The first one has been suggested by Darwin in "The descent of man" (1871). Indeed, Darwin was first to suggest that musicality may have spread in humans as an adaptive trait. His view was that, like bird songs, human musicality may have evolved in the context of sexual selection. The sexual selection theory originated from the observation that some individuals have better access to partners for reproduction than others of the same species and same sex. Thus, traits that promote attractiveness and access to partners for reproduction must be adaptive, just like those promoting survival. In this context, musicality may have evolved because it may increase mating success, for example by signaling genetic quality to potential mates (Miller 2000). Indeed, producing music may be complex and difficult, and may constitute an honest signal of several abilities including motor coordination, capacity for learning, creativity, *etc.* However, a central prediction derived from this hypothesis is that musical abilities should be positively associated with reproductive success. Evidences for such relation are weak in humans (Fitch 2005; Mosing et al, 2015), suggesting that the potential adaptive function of musicality should perhaps be sought elsewhere. Alternatively, some anthropologists have suggested that music may have evolved as a way of fostering social bonding and increasing group cohesion (*e.g*. Roederer 1984; Merker 2000; Dunbar 2017, Dissanayake 2000). We will focus thereafter on this hypothesis, which will be tested in this study.

The "group cohesion hypothesis"

Humans are a highly prosocial species. Indeed, we are regularly engaged in prosocial actions (*i.e*. actions that are beneficial for others), including actions benefitting to non-relatives (Darwin 1871; Axelrod 1984). Prosociality often leads to reciprocity, and both are fundamental features in the process of building long term social relationships, which enables group cohesion (Trivers 1971). In this context, some authors (Roederer 1984; Merker 2000; Dunbar 2017) have suggested that musicality may have spread in human populations as music may promote prosocial behavior and increase group cohesion. Indeed, music is traditionally a group activity, which may strengthen social bonds between individuals. In particular, Dunbar (2017) has proposed that music (and language later) may have served as a

sort of “acoustic grooming” in humans, replacing the usual one-on-one physical grooming that maintains relationships and is important in the stability of social groups in most non-human primates. Indeed, the increase in group size that occurred during hominid evolution may have required a more efficient social lubricant. Additionally, Falk (2004) and Dissanayake (2000) have suggested that musicality may have first emerged in the context of dyadic communication between mothers and their babies, enhancing parent-child bonding, before being generalized to other forms of communication (ceremonial rituals, adult courtship, etc.). This view is consistent with studies showing that maternal singing is unusually stable in pitch and tempo across cultures (Trehub et al. 1993), that the intense human interest in music begins from the early days of life (Trehub 2003), and that maternal singing modulates infant arousal more than maternal speech (Trehub and Nakata 2001; Shenfield et al. 2003). Infants also exhibit more sustained interest in videos showing their mothers singing than in videos showing their mother speaking (Trehub and Nakata 2001).

Regarding the proximal relationship between music and social behavior, some studies have suggested that music may influence the listener’s emotional state via neuro-hormonal mechanisms, placing the listener in good disposition for prosocial behavior (*e.g.* Freeman 1998). This hypothesis is supported by a study in mice (Angelucci et al. 2007) which found that exposure to music modulates the activity of the hippocampus, a cerebral structure that plays a major role in the processing of emotions, including social emotions (Yang and Singh 2013). Moreover, a specific feature of musical activities, which distinguishes them from other forms of social behavior, is the importance of rhythms that allows synchronization between people. Sharing a rhythm may participate in creating and strengthening social bonds amongst interacting group members (Merker et al. 2009; Tarr et al. 2014). For instance, Cirelli et al. (2018) found that interpersonal synchrony elicits helping behavior in 14-month-old babies.

From evolutionary theory to developmental psychology and education

The existing experimental support for the “group cohesion hypothesis” mostly comes from the litterature in developmental psychology. Indeed, prosocial behavior, including sharing (Brownell et al. 2013), cooperation (Warneken and Tomasello 2007), and helping (Rekers et al. 2011; Warneken and Tomasello 2006, 2007) is observed early in infant

development, from the age of 14 months (see also Hay et al. 1999). As mentioned before, developmental studies have shown that joint music production promotes helping behaviors and cooperation in 4- years old children (Kirschner and Tomasello 2010) and empathy in 8- to 11-years old children (Rabinowitch et al. 2012), and also that interpersonal synchrony elicits helping behavior in 14-month-old babies (Cirelli et al. 2018). However, the necessary conditions for music to promote prosociality in children are still unknown. In particular, the existing knowledge is scarce about the influence of listening to music (beyond music production) on social interactions, how it varies across development, and which are the specific properties of music involved (beyond interpersonal synchrony). However, a better understanding could have important outcomes, in particular for education. For instance, it could pave the way for developing the use of music at school as a pedagogic tool, helping to maintain a positive and collaborative climate for learning.

The current study

Here, we compared prosocial behavior and social interactions in 144 children from age 3 to 6, exposed to different sound stimuli: consonant music, dissonant music, and no music (*i.e*. a record of class sound as control).

First, we aimed at exploring the influence of listening to music on social behavior. In particular, we tested whether listening to music promotes prosocial behavior and positive social interactions, as suggested by the group cohesion hypothesis. By testing this hypothesis in preschool children (age 3 to 6), we also aimed at investigating the social effects of listening to music across a key period for socialization. Indeed, children learn how to behave by observing their peers and much important social skills are learnt in peer interactions. Entering preschool provides children with numerous opportunities to interact with their peers and is thus an important step in the development of their social abilities (Mize and Ladd 1990). Prosociality in preschool children has often been studied using resource sharing tasks. Indeed, several authors have asked preschool children to allocate a resource (for instance, some stickers) between themselves and another child (or a puppet). They found that most preschool children prefer to share equally and that they react negatively to unfair distributions (LoBue et al. 2011; McAuliffe et al. 2013; Shaw and Olson 2012, 2013). However, when the items to allocate vary in terms of rarity or value, preschool children are

more likely to keep the rarest or more valuable resource than to give it (Chernvak and Sobel 2015). To our knowledge, nothing is known about the influence of listening to music on these sharing behaviors, as well as on other prosocial behaviors like cooperation and helping. How these influences may vary according to age is also a remaining question.

Second, we aimed to test the role of consonance as a key property involved in the relation between listening to music and social behavior. In music, consonance commonly refers to some note intervals that are generally perceived as pleasant, whereas dissonant intervals are generally perceived as unpleasant (*e.g*. Trainor et al. 1998). Indeed, except rare exceptions (*i.e.* one study conducted in a native Amazonian tribe, the Tsimanes, showed that they do not discriminate between consonant and dissonant music, Mc Dermott 2016), a preference for consonance is generally observed in humans, even in very young infants (*e.g.* Trainor et al. 1998; Masataka 2006). Consonant and dissonant music may thus influence social behavior differently, in particular if the relationship between listening to music and social interactions is mediated by the feeling of pleasure associated with the listening activity. Indeed, endorphins are argued to mediate the pleasure experienced when listening to music (Huron 2006; Koelsch 2010), and they are also known to play a major role in the maintenance of social bonds (Machin and Dunbar 2011). Listening to consonant music being a more pleasant experience than listening to dissonant music, it may thus have a stronger positive influence on social interactions.

Third, we aimed at taking forward the debate of whether musicality emerged in humans as an evolutionary adaptation or a cultural invention. To this end, the results will be discussed in light of those obtained in other studies focusing on musicality in other species.

Materials and methods

Participants

A sample of 144 children was recruited in two French urban preschool boards to participate in this study. They were divided into three groups according to their preschool grades: first grade (age 3.22 to 4.38, M = 3.75, SD = 0.61, n = 48, 24 girls), second grade (age 4.32 to 5.48, M = 4.83, SD = 0.74, n = 48, 24 girls) and third grade (age 5.3 to 6.36, M = 5.83,

SD = 0.31, n = 48, 24 girls). Children were tested in pairs. The two children in a pair were always recruited from the same school and the same class, and we asked help from their teachers to avoid pairing together any best friends or children with conflictual relationships. In order to reduce possible biases, we only paired children of the same gender and of less than three months age difference. Each pair was randomly assigned to one of three conditions (consonant music, dissonant music, or control), leading to a final sample size of 16 children per each age group-condition combination. Signed informed consent was obtained from a parent or legal guardian for each participant. The children also assented to participate orally. In addition to signing the consent form, the parents or legal guardians also answered a short questionnaire about the child, including age, sex, number of siblings, and the two following questions: “Does the child practice any extracurricular activity related to music? (practice of a musical instrument, dance, initiation to music, …)”, and “Does the child sometimes hear classical music at home?”. The answers were used as control variables in the statistical analyses, as described below.

Stimuli

Three sound stimuli were used, corresponding to three different conditions: consonant music, dissonant music, and control. The consonant and dissonant stimuli were taken from Koelsch et al. (2006). The consonant stimulus was built out of ten excerpts of joyful instrumental dance-tunes from the last four centuries (Table 1). Each excerpt was one minute long. To create the dissonant stimulus, the original tunes were electronically manipulated using CoolEdit Pro software. They have been recorded simultaneously with two pitch-shifted versions, which were one tone above and a tritone below the original pitch. Both consonant and dissonant versions of an excerpt had the same dynamic outline, identical rhythmic structure, and identical melodic contour (Koelsch et al. 2006). Koelsch et al. (2006) used these stimuli to compare, in a fMRI study conducted with adult participants, the effects of pleasant (*i.e*. consonant) and unpleasant (*i.e*. dissonant) music on activation of the cerebral structures involved in emotion processing. The two stimuli led to activation of distinct structures, suggesting that they are different enough to elicit distinct emotional reactions. Finally, we used a record of class noise as a control. This way, when listening to consonant or dissonant music, children's behaviors were compared with those observed when listening to a familiar sound, mimicking their daily sound environment at school. To create the control record, we recorded the ambient noise in a classroom for thirty minutes, during a recreational moment. We then processed the record using Adobe premiere CC 2015 in order to delete any part with recognizable or understandable voices and to keep only the background noise.

Table 1. List of the excerpts included in the stimuli

Order	Time	Composer, name
1	00 – 00:56	Anonymous, Entree-Courante
2	00:56 – 01:55	J.S. Bach, Badinerie (Overture No. 2, BWV 1067)
3	01:55 – 02:38	J.S. Bach, Bourrée (Overture No. 1)
4	02:38 – 03:38	P. Castellanos, La Puñalada
5	03:38 – 04:29	P.F. Caroubel, Volte
6	04:29 – 05:27	A. Dvorák, Slavonic Dance No. 8 in G Minor (Op. 46)
7	05:27 – 06:20	A. Dvorák, Slavonic Dance No. 1 in B Major (Op.72)
8	06:20 – 07:07	V. Haussmann, Catkanei
9	07:07 – 08:07	Pee Wee Ellis, Soul intro ("The Chicken")
10	08:07 – 09:05	J.S. Bach, Réjouissance (BWV 1069)

Study design

All testing was done at school, in the morning, by the same experimenter and assistant (the two first authors). The experiments were filmed for the purpose of the analyses using a Sony Handicam HDR- CX410 camera. The experimenter and the assistant strictly followed the same script to demonstrate the consecutive actions and instruct each pair of children. The experiments with each pair of children were composed of two consecutive steps – (1) listening only, and (2) prosocial tasks (while the stimuli continued to be played back). First, the experimenter asked the children to sit down with her in order to "listen to something while the assistant is setting up some new games". One of the stimuli (either consonant music, dissonant music or control) was then diffused using a bluetooth speaker, with

constant volume (55-65 dB). Seven minutes later, the experimenter told the children that the games were going to start. The children then performed three prosocial tasks designed to test sharing, cooperation and helping, respectively.

For the sharing task (**Figure 1**), each child had to share allocations (stickers) with the other child of the pair. To prevent any bias on the sharing behavior due to the presence of the other child in the room, the children were tested one after the other following the same procedure (while one child was tested by the experimenter, the other waited outside with the assistant). Each child was presented with seven stars shape stickers of seven different colors (blue, pink, red, grey, orange, purple and yellow) and two pots to put the stickers in. One of the pots was identified by the experimenter as belonging to the tested child and the other to the child waiting outside. One of the stickers was two-fold larger than the others (2 inches), and color- size combinations were randomized for each child. Each child was told to decide how to allocate the stickers between him or herself and the other child by putting the stickers in the pots. Dependent variables were the number of stickers given, the allocation of the largest one (given or kept), hesitations (yes if at least one sticker was shifted from one pot to the other, no if not), equity (Does the child share as equitably as possible, *i.e.* give either three or four stickers among seven), and duration of the task (time interval in seconds between stickers presentation and the moment when the last sticker was put into a pot).

Figure 1. Sharing task

For the cooperation task, children were asked to cooperate by pulling on two strings in synchrony in order to scoot out a drawer with two pots attached to it, each containing a reward (stickers). The task was designed such as if only one string was pulled out, the drawer

did not move. The apparatus is shown in **Figure 2** and was inspired from Hamann et al. (2011). Before the children could manipulate the strings, the experimenter and her assistant demonstrated the action needed in order to succeed the task: first the experimenter explained to the children that the pots contain rewards and that in order to get them, they should pull the drawer out. Then she tried to pull on the string alone showing that the drawer did not move and, five seconds later, the assistant came and pulled the second string in synchrony resulting in pulling the drawer successfully from position A to position B. After the demonstration, the experimenter moved the drawer back to its initial position and the children were left alone in the room to avoid any third-party influence. The task ended when the children successfully retrieved the drawer or after two minutes of manipulation. We coded the duration of the task (time interval between the first time the two children held the strings and the moment when the drawer reached position B) and the number of mutual looks, mutual laughs and verbal interactions per second.

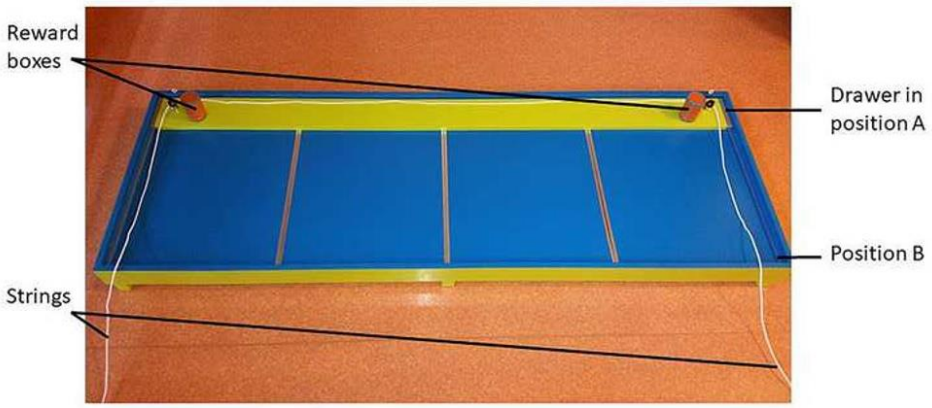

Figure 2. Cooperation task

For the helping task (**Figure 3**), as in Kirschner and Tomasello (2010), we created a situation in which one of the children had a sudden accident that presented the partner with the choice to help or to continue his or her own activity. To this end, we developed a detailed background story involving two little ducks who were very hungry and needed to be fed. The ducks were represented by two little toys previously placed into two distinct baskets (the "ponds"). Five meters away from the ponds were placed two supports containing two plastic tubes each, one white and one coloured (red or black), and two

containers containing seven white balls and seven coloured balls (red or black) each **(Figure 3)**. First, as a part of the story, the children were asked to put the balls in the appropriate tube matching the colours, pretending that the balls were to feed the ducks and that they had to be transported using the tubes. The white balls in the white tubes were used by the experimenter to demonstrate twice how to "feed the ducks". Then, each child was randomly assigned to a color, either black or red and both children were asked to carry out their tube from the support to one of the two ponds and to spill the balls in it. However, we had prepared the black tube (broken tube) so that the bottom fell out and all seven balls were spilled on the floor. This manipulation allowed us to assess helping behaviors from the child who had the red tube (not manipulated). In particular, we assessed whether the "helper" (*i.e*. the child assigned to the red tube) stopped his/her activity and whether he or she helped the other child by picking up some balls. We also assessed the number of balls picked up by the helper, if any. The children were left alone in the room during the task to avoid any third-party influence.

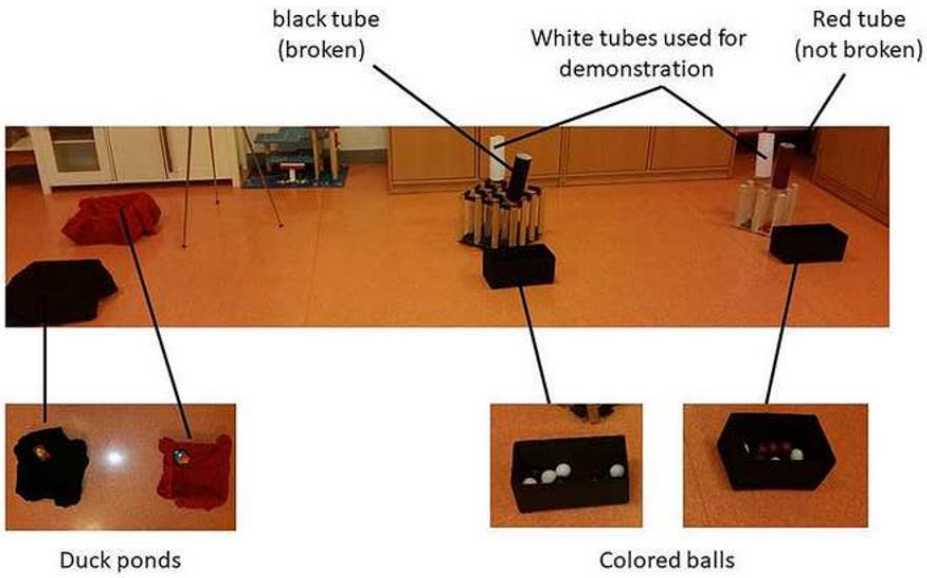

Figure 3. Helping task

The three tasks were performed in the same order (sharing, then cooperation, and then helping) for all pairs. The sharing task was performed first as it was done individually, and the children did not know after the task how the partner allocated the stickers. This task was

thus less likely than the others to influence later behaviors and interactions during the other tasks. On the opposite, the helping task was the last to be performed as being helped or not by the partner is likely to influence a child's subsequent behavior toward his or her partner.

Coding

All videos were coded by the same coder, using the VLC Media Player software. To assess inter-rater agreement, 20% of them were independently coded by another coder. We reached an inter-rater agreement of κ=0.97 for the sharing task, κ=0.89 for the cooperation task, and κ=0.99 for the helping task.

Statistical analyses

Each dependent variable was analyzed in generalized linear mixed models (GLMM), using the R program v3.4.3 (R Core Team 2017) and the add-on package lme4 (Bates et al. 2014). The following variables were included in all models as fixed effects: Condition, Grade, Condition in interaction with Grade, Sex, Does the child practise or have practised any extracurricular musical activity (yes / no), Does the child regularly hear classical music at home (yes / no), and Does the child have siblings (yes / no). Moreover, for the sharing task, we also included the Order of testing as a fixed effect. Finally, all models included the Preschool institution and Class as nested random effects. In order to maximize model likelihood and to eliminate any unnecessary fixed terms, we used a backward stepwise approach: we started with all the fixed terms (main effects and interactions), tested deletion of each one, deleted this term if deletion improved the model's likelihood, and repeated the process until no further improvement was possible. We used the "Anova" R function to test for significant improvement of the model's likelihood, and also to obtain p-values for the fixed effects included in the final model, based on Likelihood Ratio Tests (LRT). In addition, we used post-hoc Tukey tests (Tukey 1949) to perform pairwise comparisons among the three conditions. Finally, when a significant effect of the Condition:Grade interaction was detected, we performed additional GLMM analyses within each grade to investigate which pairs of conditions differed significantly for each grade. These models included the same fixed and random effects as above, except Grade and Grade:Condition.

Results

The detailed results of the GLMM analyses for the three tasks are reported in **Table 2.**

Sharing task

Regarding the sharing task, as shown in table 2, second grade children took significantly less time to complete the task than first and third grade children, although they were more likely to switch stickers from a pot to another (hesitations). Condition also had a significant effect on these variables. Indeed, children listening to consonant music took more time to complete the task and hesitated more than those in the control condition. The dissonant condition led to intermediate values for these two variables, with no significant differences as compared to the consonant or the control condition. However, the tested variables had no significant effects on the level of sharing (number of stickers given), on the probability that a child gave the largest sticker, or on the probability that a child shared as equitably as possible.

Table 2. Results of the GLMM analyses conducted with the whole sample. (following pages)

Task	Dependant variable	Fixed effects in the final model	Means [a]
Sharing	Duration of task(in seconds)	**Grade**	1st: 41.14 s; 2nd: 21.08 s; 3rd: 40.89 s
		Condition	CM: 42.97 s; DM: 37.70 s; C: 28.37 s
	Hesitations (yes/no)	**Grade**	1st: 20.83%; 2nd: 58.33% s; 3rd: 18.75 s
		Condition	CM: 45.83%; DM: 37.5 %; C: 14.58 %
	Number of stickers given	none	_
	Is the largest sticker given?	none	_
	Equity	none	_
Cooperation	Duration of task (in seconds)	**Condition:Grade**	_
		Sex	Girls: 31.3 s; Boys: 13.85 s
		Having siblings	Yes: 22.74; No: 23.19
		Musical practice	Yes: 16.19 s, No: 24.34 s,
	Mutual looks (per second)	**Condition:Grade**	_
	Mutual laughs (per second)	**Condition:Grade**	_
	Verbal interactions (per seconds)	**Condition:Grade**	_
		Musical practice	Yes: 0.04; No: 0.02
		Familiarity to classical music	Yes: 0.01; No: 0.03
Helping	Waiting (yes/no)	Grade	1st: 0.01; 2nd: 0.12; 3rd: 0.09
	Picking up (yes/no)	None	_
	Number of balls picked up	None	_

χ^2	DF	*p*	Tukey tests		
13.41	2	**0.001**	**1st - 2nd: 0.002**	**2nd - 3rd: 0.003**	1st - 3rd: 0.86
9.22	2	**0.01**	**CM - C: 0.01**	DM – C : 0.08	CM - DM: 0.92
13.45	2	**0.001**	**1st - 2nd: < 0.001**	**2nd - 3rd: 0.001**	1st - 3rd: 0.76
10	2	**0.007**	**CM - C: 0.008**	DM - C: 0.07	CM - DM: 0.61
–	–	–	–	–	–
–	–	–	–	–	–
–	–	–	–	–	–
721.35	8	**< 0.001**	–	–	–
171.07	1	**< 0.001**	–	–	–
94.41	1	**< 0.001**			
20.07	1	**< 0.001**	–	–	–
78.97	8	**< 0.001**	-	–	–
40.92	8	**< 0.001**	–	–	–
23.92	8	**0.002**	–	–	–
8.56	1	**0.003**	–	–	–
18.92	1	**< 0.001**	–	–	–
7.21	2	**0.03**	1st - 2nd :0.88	2nd - 3rd: 0.14	1st - 3rd: 0.21
–	–	–	–	–	–
–	–	–	–	–	–

[a] **CM: Consonant Music; DM: Dissonant Music, C: Control**

Cooperation task

All children succeeded in this task. However, as shown in T**able 2**, both male sex, having siblings or practising a musical activity are associated with less time to complete the cooperation task. Moreover, practising a musical activity is associated with more verbal interactions, whereas familiarity with classical music is associated with less verbal interactions. Finally, we found significant effects of the Condition: Grade interaction on all dependant variables (duration of the task, mutual looks, mutual laughs, and verbal interactions). To help interpreting these interaction effects, we conducted separated GLMM analyses for each grade. The results of these analyses are reported in **Table 3** and illustrated in **Figure 4**. In particular, we found that first grade children took more time to complete the task when they were listening to music (either consonant or dissonant) as compared to the control noise. In contrast, we found no significant effects of condition on the duration of the task in second grade nor in third grade children. First grade children in the music conditions (either listening of consonant music or listening of dissonant music) also had more mutual looks per second than those in the control condition. Moreover, second grade children in the consonant music condition had both more mutual looks and more mutual laughs than those in the dissonant music condition or those in the control condition. Finally, third grade children in the consonant music condition had more verbal interactions than those in the dissonant music condition or those in the control condition.

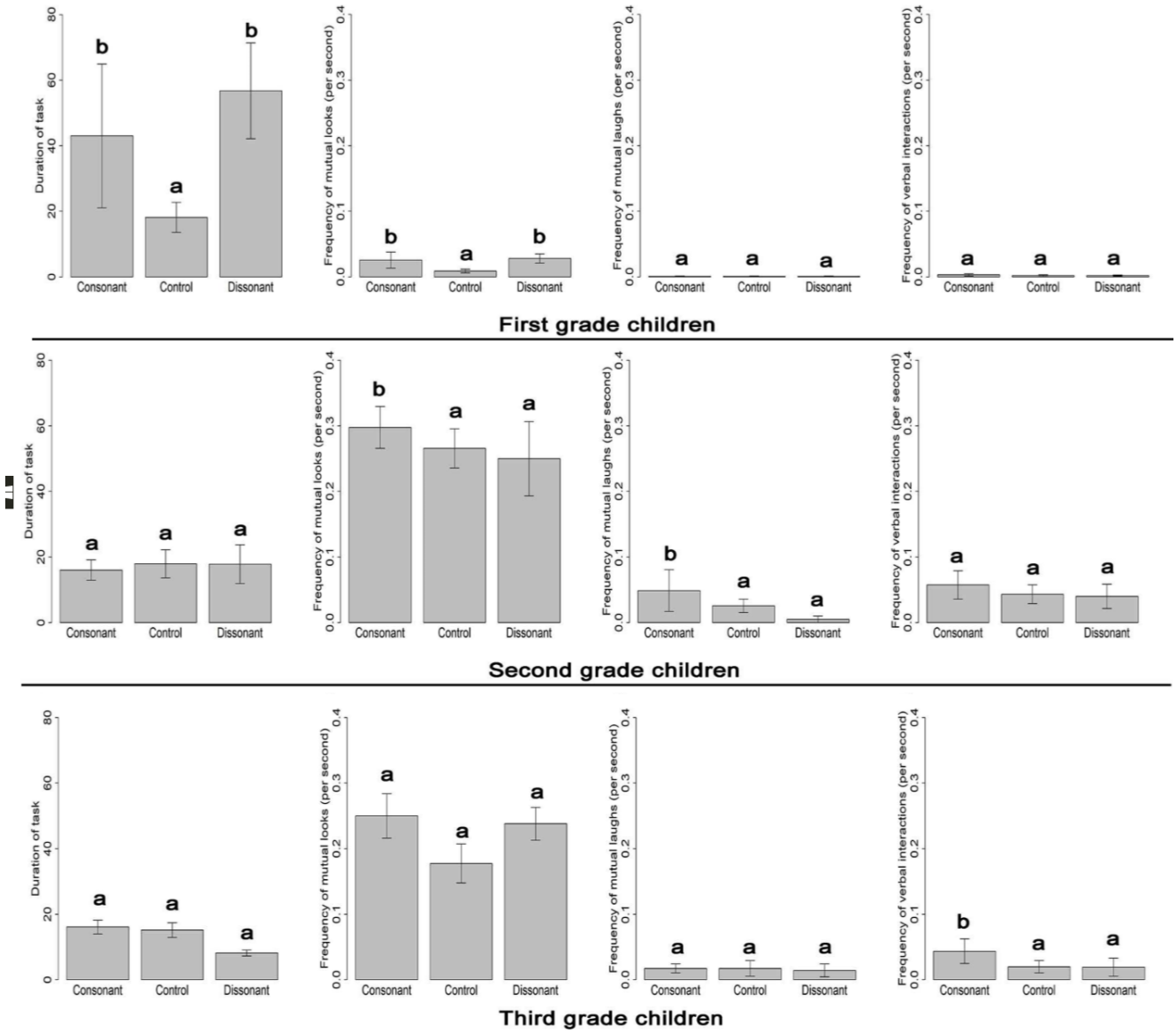

Fig 4 Effects of listening to consonant and dissonant music on behavior during the cooperation task

[a,b] Different letters indicate a significant difference (p <0.05)

Helping task

Finally, as shown in **Table 2**, we did not find any significant effects of the analysed variables on the behavior observed during the helping task. In particular, the Tuckey tests revealed no significant pairwise differences among grades for the probability of waiting for the partner in difficulty. Moreover, the other tested variables had no significant effect on this probability, and none of the tested variables had any significant effects on the probability to pick up some balls and the number of balls picked up.

Discussion

The aim of this study was to investigate the influence of listening to music on social interactions in preschoolar children. We also explored how this effect varies across development, by comparing three age groups defined by preschool grade (first grade: age 3 to 4, second grade: age 4 to 5, third grade: age 5 to 6). Moreover, we compared the effects of listening to consonant or dissonant music, in order to test whether consonance is one of the musical properties involved in the relation between listening to music and social behavior. Finally, our results also give insights on how musicality emerged in human evolution.

Musical influences on social interactions

Regarding the sharing task, we did not find any effect of listening to music on the level of sharing nor on the probability to share the most rare and valuable resource (*i.e*. the biggest sticker). However, children listening to consonant music took more time to complete the sharing task and hesitated more (*i.e*. did more switches from one pot to another) than those listening to the control sound. A possible explanation is that children listening to consonant music might pay more attention in sharing equally than those listening to the control sound. However, our results bring only limited support to this hypothesis as we did not find any differences in equity (*i.e.* probability to share as equally as possible) among conditions. Alternatively, the children may have been more distracted by the consonant stimulus, as they may pay more attention to consonant music than to a control noise. Nevertheless, note that some methodological issues may make the results of the sharing task difficult to interpret. In particular, in order to control for the influence of color preferences on sharing decisions, we decided to present to each child seven stickers of different colors. Moreover, one of the stickers was two-fold larger than the others, in order to assess the percentage of children who share the most rare and valuable resource. However, this procedure may have both complicated the children's choices and led to poorly interpretable results. For instance, it is not clear whether a child who shares two stickers including the biggest one was less concerned with equity than a child who shared three little stickers. Simplifying the sharing task may be useful for future studies, for instance by asking each child to choose one colour

and then to divide seven identical stickers of the chosen colour between himself or herself and the partner (*e.g*. Liu et al. 2015; Posid et al. 2015).

Regarding the cooperation task, we found significant positive effects of listening to music on social interactions. In 2010, Kirschner and Tomasello already found that joint music making promotes subsequent cooperative (and helping) behavior in 4 years-old children. Here, by showing that listening to music together also influences cooperative behavior, we thus went a step further. More precisely, although all the participants succeeded in the cooperation task, the duration of the task as well as the nature and frequency of social interactions between the children vary substantially depending on multiple factors. Male sex, having siblings or practising a musical activity were associated with less time to complete the task. Moreover, practising of a musical activity was associated with more verbal interactions related to the task. This might be related to the fact that musical practice in children has multiple positive effects on the development of cognitive and communication abilities (Hallam 2010). In particular, musical training influences the cortical processing of linguistic pitch patterns (Schön *et al,* 2004), and thus helps to develop better language abilities (*e.g.* vocabulary richness, Piro and Ortiz, 2009). In contrast, familiarity with classical music was associated with less verbal interactions. This might indicate that children who are familiar with listening to classical music pay more attention to the music and thus interact less during the task. Most interestingly, both duration of the task and the nature and frequency of social interactions between the children were also influenced by an interaction effect between school grade and condition. In particular, first grade children had more mutual looks and took more time to complete the task when listening to music (either consonant or dissonant) rather than the control sound.

Table 3. Results of the GLMM analyses conducted within grades for the cooperation task. (Following pages)

Grade	Dependent variable	Fixed effects in the final model	Means [a]
1st	Duration of task	**Condition**	CM: 43 s; DM: 56.71 s; C: 18.14 s
		Sex	Boys: 21.35 s, Girls: 54.54 s
		Siblings	Yes: 36.21 s, No: 60 s
		Musical practice	Yes: 36 s, No: 39.62 s
	Mutual looks	**Condition**	CM: 0.03 ; DM: 0.03 ; C: 0.008
	Mutual laughs	None	_
	Verbal interactions	**Musical practice**	Yes: 0.01; No: 0.002
		Familiarity to classical music	Yes: 0.002; No: 0.003
2nd	Duration of task	**Condition**	CM: 16 s; DM: 17.81s; C: 17.94 s
		Sex	Boys: 10.83 s, Girls : 23.67 s
		Siblings	Yes: 19.12 s ; No: 12.71 s
		Musical practice	Yes: 18.63 s ; No: 16.98 s
		Familiarity to classical music	Yes: 13.64 s ; No: 18.32 s
	Mutual looks	**Condition**	CM: 0.28 ; DM: 0.25; C: 0.26
	Mutual laughs	**Condition**	CM: 0.05 ; DM: 0.005; C: 0.03
	Verbal interactions	**Musical practice**	Yes: 0.06 ; No: 0.04
3rd	Duration of task	Condition	CM: 16.12 s; DM: 8.19 s; C: 15.18 s
		Sex	Boys: 10.62 s, Girls: 15.71 s
		Familiarity to classical music	Yes: 17.37 s; No: 12.32 s
	Mutual looks	**None**	**_**
	Mutual laughs	**Musical practice**	Yes: 0 ; No: 0.02
	Verbal interactions	**Condition**	M: 0.04 ; DM: 0.02; C: 0.02

χ^2	DF	*p*	Tukey tests		
13.97	2	**< 0.001**	**CM - C: 0.01**	**DM - C < 0.001**	CM - DM: 0.51
98.28	1	**< 0.001**	_	_	_
76.99	1	**< 0.001**	_	_	_
61.83	1	**< 0.001**	_	_	_
18.18	2	**< 0.001**	**CM – C < 0.001**	**DM - C < 0.001**	CM - DM: 0.33
–	–	–	–	–	–
14.97	1	**< 0.001**	_	_	_
12.57	1	**< 0.001**	_	_	_
7.09	2	**0.03**	CM - C: 0.12	DM - C: 0.16	CM - DM: 0.13
89.25	1	**< 0.001**	_	_	_
14.64	1	**< 0.001**	_	_	_
6.41	1	**0.01**	_	_	_
4.4	1	**0.04**	_	_	_
6.13	2	**0.04**	**CM - C: 0.02**	DM - C: 0.23	**CM - DM: 0.03**
8.21	2	**0.02**	**CM - C: 0.01**	DM - C: 0.34	**CM - DM: < 0.001**
16.47	1	**< 0.001**	_	_	_
34.86	2	**< 0.001**	CM - C: 0.13	DM - C: 0.09	CM - DM: 0.12
11.97	1	**< 0.001**	_	_	_
5.7	1	**0.02**	_	_	_
–	–	–	–	–	–
8.89	1	**0.003**	_	_	_
7.64	2	**0.02**	**CM - C: 0.01**	**DM – C : 0.018**	**CM – DM : <0.01**

[a] **CM: Consonant Music; DM: Dissonant Music, C: Control**

This may indicate that children may pay more attention to cooperate and to synchronize their movements with those of the partner when listening to music rather than a control sound. Similarly, second grade children listening to consonant music had more mutual looks and more mutual laughs than those listening to the control sound or to the dissonant music. Regarding third grade children, those listening to consonant music had more verbal interactions than the others. As mentioned before, from a mechanistic point of view, the relationship between listening to music and positive social interactions may be mediated by endorphin production. From an evolutionary point of view, the finding that listening to music promotes positive social interactions supports the idea that musical abilities may have emerged in humans as an adaptation promoting group cohesion. We will come back later to this point, as well as to the roles of age group and consonance in the social effects of listening to music.

Finally, we did not find any influence of listening to music on behavior during the helping task (*i.e*. on the probability of waiting for the partner in difficulty, the probability of helping the partner, or the level of helping). In contrast, Kirschner and Tomasello (2010) found joint music production to promote helping in four years old children. This discrepancy might indicate that listening to music together, contrary to producing music together, might not promote helping behavior. However, this result has to be interpreted with caution. Indeed, our sample size for this task was two-fold lower than for the other tasks, as only one child per dyad was confronted to the choice of waiting, helping or ignoring the partner. Small sample size (eight children per age group and condition combination) may have limited the statistical power of the analyses. In particular, this may explain the fact that we were not able to detect significant pairwise differences among grades for the probability of waiting for the partner in difficulty, despite an overall significant effect.

Variation across development

In adults, some studies have already suggested an influence of listening to music on social interactions. For instance, North et al. (2004), in a study involving 646 users of a university gym, found that playing back uplifting music rather than annoying music increased the participant's probability to accept signing a petition in support of a charity and distributing leaflets on their behalf. Lang et al. (2016) also found listening to religious music to

discourage dishonest behavior in religious people. Finally, Greitemeyer (2009) found listening to songs with prosocial lyrics to increase empathy and helping behavior. In contrast, to our knowledge, our study is first to demonstrate an influence of listening to music on social interactions in children, and to give insights on how these effects vary across child development. In particular, although we found some effects of listening to music on social interactions during the cooperation task in the three studied age groups, we also demonstrated that listening to music promotes different categories of social interactions according to age (mutual looks in first grade children, both mutual looks and mutual laughs in second grade children, and only verbal interactions in third grade children). This may reflect the fact that older children rely more on verbal interactions to communicate whereas younger children tend to preferentially use physical imitation (Nadel and Baudonnière 1980).

The role of consonance

The fact that we found similar effects of consonant and dissonant music on social interactions during the cooperation task in first grade children is unlikely to result from a lack of perception of consonance and dissonance before the age of four. Indeed, some studies found discrimination between consonance and dissonance (and preference for consonance) even in very young infants (2 to 4 months old, Trainor et al. 1998; and even 2 days old, Masataka 2006). Rather, although first grade children are probably able to perceive a difference between consonant and dissonant music, the two types of music may differ in their effects on social behavior in older children only. More investigation focusing on the influence of consonant and dissonant music on neural processes at different ages would be needed to understand the underlying causal mechanisms. For instance, the preference for consonance compared to dissonance may become stronger over development, perhaps being reinforced by cultural constructs.

Moreover, the fact that consonant and dissonant music differed in their effects on social interactions during the cooperation task in second and third grade children is especially interesting, as it suggests that consonance is a key property of music involved in its effects on social behavior. This result is consistent with a fMRI study performed in adults by Koelsch et al. (2006). They used the same musical stimuli as in the present study and found pleasant (defined as consonant) and unpleasant (defined as dissonant) music to differ in their effects

on the activation of several cerebral structures implicated in emotion processing (amygdala, hippocampus, parahippocampal gyrus and temporal poles). Additional investigation would be needed to identify other properties which may also be involved. For instance, several studies have suggested a major role of rhythm and interpersonal synchrony (Merker et al. 2009; Tarr et al. 2014). Notably, Cirelli et al. (2018) found that interpersonal synchrony promotes helping behavior in 14-month-old babies. Future studies may bring insights on how interpersonal synchrony influences other social behavior and how this effect varies across child development.

Is music an evolutionary adaptation or a cultural creation?

Some studies focusing on non-human species, in particular on birds, suggest that musicality (*i.e.* abilities for music perception, appreciation and production) may not be unique to humans. For instance, many bird species sing according to precise rules, some of them being very similar to those inducing emotions in human listening to music (Rothenberg et al. 2014). Moreover, several studies found some forms of musicality in songbirds and parrots. Java sparrows can discriminate between consonance and dissonance (Watanabe et al. 1998), African grey parrots have musical preferences (Péron et al. 2008) and can create new songs from new musical stimuli (Bottoni et al. 2003), and cockatoos can spontaneously synchronize themselves with changing rhythms (Patel et al. 2009). Rather than being a purely cultural human invention, musicality may thus have emerged as a biological feature in at least two groups during the evolutionary course of life : humans and birds. In this context, showing that listening to music promotes positive social interactions in humans allow going a step further in our understanding of the evolutionary pressures that may have triggered the emergence of musical abilities in our species. Indeed, it brings support to the “group cohesion hypothesis”, *ie*. the idea that a positive influence of music on social interactions may have mediated a positive relationship between musical abilities, group cohesion, and thus survival and/or reproductive success (Roederer 1984; Merker 2000; Dunbar 2017).

Perspectives

This study demonstrates that listening to music influences social behaviors in preschool children, and thus opens new perspectives. In particular, we hope to pave the way for future studies aiming to understand the necessary conditions for music to promote social interactions. For instance, does the listening experience have to be shared to promote social interactions, does it promote social interactions only between the individuals who listened together or also between them and other peers, what are the properties of music (beyond consonance) and the proximal mecanisms involved… all these questions remain to be answered in order to understand better the influence of music on social behaviors. This may also pave the way for developing the use of music to increase welfare. For instance, playing back consonant music at school, as well as conducting musical activities, may help to maintain a positive and collaborative climate for learning by promoting positive interactions among children and between children and their teachers.

In addition, this study brings support to the hypothesis that musicality may have evolved in humans as an evolutionary adaptation promoting group cohesion. As mentioned before, some other species, in particular some birds, also have some musical abilities. However, the issue of whether musicality has evolved with the same adaptive function (promoting group cohesion) in humans and birds is still open, and this question could be addressed using a comparative approach. Note that musical abilities are much more limited in non-human primates, although they are phylogenetically closer to us than birds. For instance, although marmosets and tamarins prefer slow tempi rather than fast ones, they overall prefer silence (McDermott et al. 2006). Orangutans also prefer silence to music according to Ritvo and McDonald (2016). Moreover, even after a long (one year) training, monkeys synchronize their tapping with a metronome with less accuracy and more time variability than humans (Zarco et al. 2009). This information is important as it indicates that musicality in humans is a derived character (*ie.* emerged into the human lineage, after the divergence between humans and our closest relatives), rather than an ancestral one (*ie*. more ancient). Musicality is thus not shared by humans and birds because it would have emerged in a common ancestor. However, musicality may have evolved convergently at least two times during the evolutionary history of life, in humans and in birds, with a similar adaptive function in the two groups: promoting positive social interactions and group cohesion. This hypothesis

could be tested by investigating whether listening to music also promotes positive social interactions in bird species with musical abilities, like in humans.

Compliance with Ethical Standards

Funding: Carla Aimé has received a postdoctoral grant from COMUE Université Paris Lumières for this work.

Conflicts of interest: The authors declare that they have no conflict of interest.

Informed consent: For each child participant, signed informed consent was obtained from a parent or legal guardian. The children also assented to participate orally.

Ethical approval: All procedures performed in this study involving human participants were in accordance with the ethical standards of the institutional and/or national research committee and with the 1964 Helsinki declaration and its later amendments or comparable ethical standards.

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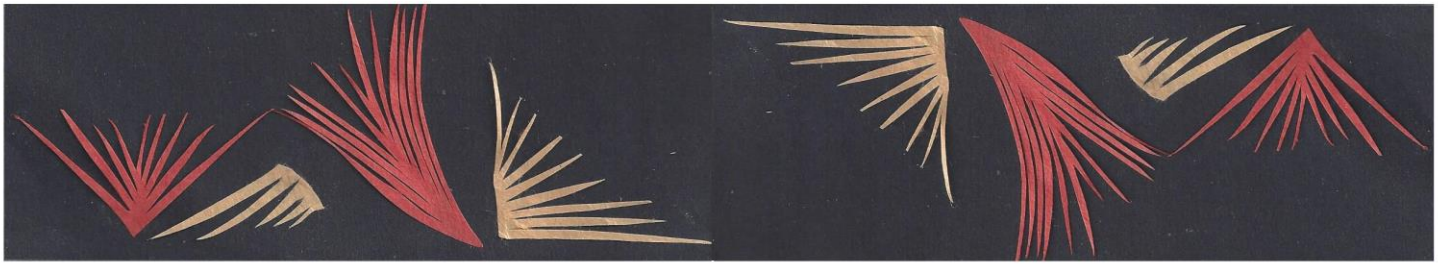
Chapitre II : Préférences musicales chez les calopsittes élégantes et les corbeaux à gros becs



2.1. Chez les calopsittes élégantes

Musical preferences, indifference to the consonance / dissonance feature and personality in cockatiels

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Acknowledgements

We thank O. Bouillet, P. Groué and E. Martin for taking care of the birds. We also thank Heiko Rodel and Jean-Luc Durand from the LEEC (Paris 13) for their advises in statistical analysis.

Abstract

Music may be one of the oldest forms of art and its appreciation is thought to be universal in humans. The ability to discriminate between different kinds of music or composers has already been evidenced in numerous non-human species, yet a reinforcing effect of music was found only in a few species; it is especially the case for vocal learners like passeriformes or psittaciformes. In this study, we explored musical preferences and their relationship with personality in cockatiels, depending on several musical features. We provided the birds with a touch screen allowing them to choose between either rock or calm music, then between consonant or dissonant music. The results showed some individual preferences for rock or calm music but an indifference to the consonance / dissonance feature. Those results support the hypothesis whereby vocal learners would be sensitive to music, but suggest that the preference for consonance may not exist in cockatiels, or could be related to experience. Given that only a few birds interacted with the device, correlating

musical preferences and personality is uneasy. Yet, our findings can provide further prospects for the study of musicality in non-human animals and welfare of captive species.

music ; welfare; birds ; psittaciformes; cacatuidae; parrots

Introduction

Music may be one of the oldest forms of art. To date, the earliest musical instrument ever discovered is a bone pipe that would be 45, 000 years old (Tuniz et al. 2012). According to Watanabe et al. (2009), music is likely to have a long history, given that it exists in every human culture (Merriam and Merriam 1964) including people with traditional lifestyles; its appreciation is thought to be universal (Watanabe et al. 2009; McDermott and Hauser, 2005; Sugimoto et al. 2010).

The relationship between music and emotions has been explored in several studies: musical excerpts can be classified depending on the mood they trigger (Skowronek et al. 2006) and pleasure in response to musical experience is linked to dopamine activity in the mesolimbic reward system (Salimpoor er al. 2011). Besides, an experiment evidenced that extreme music increased positive emotions in extreme music fans, helping them to process their emotions, which suggests an importance of one's personal musical preferences on welfare (Sharman and Dingle 2015).

We also know that in humans, there is a correlation between musical preferences and personality (Rentfrow and Gosling 2003): for example, adolescents like better music reflecting their personality features (Schwartz and Fouts 2003) and extraverts prefer emotional music compared to introverts (Veltri 2016).

Musicality in non-human animals

Music is often considered as a human specificity (see for example Dutton 2006 ; D'Azevedo 1958 and Godt 2005). However, even Darwin (1871) suggested that there would

be a “sense of beauty” shared by different species, explaining for example why we find beautiful the songs of birds. Yet, music is a complex notion, for which no definition consensus has been found to date. The concept of musicality is broader and might be thus easier to explore; musicality is described by Hoeschele et al (2016) as “the capacity that makes it possible for us to perceive, appreciate and produce music”. As it happens, we share similar perception features with non-human animals: melody perception, for example, would be driven by several perceptual strategies, including relative and absolute pitch, in different species (Hulse et al.1992).

Musicality (or other aesthetic stimuli) can be studied in non-human animals via different levels, some of them being described by several authors (Otsuka et al. 2009; Watanabe and Kuczaj 2013): (1) the cognitive or discriminative level, i. e. the ability to discriminate between different kinds of music or different composers and (2) the reinforcing level, i. e. the ability to be reinforced or to feel pleasure when listening to musical stimuli, but also to show musical preferences.

Some studies have already evidenced the discriminative level for rhythm or music in numerous non-human species: starlings (Hulse et al. 1984), jackdaws (*Corvus monedula*) (Reinert 1965), zebra finches (*Taeniopygia guttata*) and budgerigars (*Melopsittacus undulatus*) (ten Cate et al. 2016) for rhythm and pulse; elephants (*Elephas maximus*) (Reinert 1957), rats (*Rattus norvegicus*) (Poli and Previde 1991 ; Otsuka et al. 2009), pigeons (*Columba livia*) (Porter and Neuringer 1984), common starlings (*Sturnus vulgaris*) (Hulse et al. 1995), Java sparrows *(Lonchura oryzivora)* (Watanabe and Nemoto 1998), Japanese macaques (*Macaca fuscata*) (Izumi 2000), common carps (*Cyprinus carpio*) (Chase 2001) and goldfishes (*Carassius auratus*) (Shinozuka et al. 2013) for music; yet only a few of them revealed a reinforcing effect of music.

As it happens, non or limited vocal learners like pigeons (Watanabe et al. 2009), hens (*Gallus gallus domesticus*) (McAdie et al. 1993), rats (Crespo-Bojorque and Toro 2015) or goldfishes (Shinozuka et al. 2013) do not show musical preferences. Given that they are phylogenetically very close to us, several studies also explored musicality and more specifically musical preferences in apes and monkeys, which are limited vocal learners (Janik and Slater 1997). Those studies show contrasted results: although chimpanzees prefer African and Indian music over silence (Mingle et al. 2014) and one baby female chimpanzee

preferred consonance over dissonance (Sugimoto et al. 2010), marmosets, tamarins (McDermott and Hauser 2007) and orang-utans (*Pongo abelii)* (Ritvo and McDonald 2016) prefer silence to music. On the contrary, the results with vocal learners seem more promising: Java sparrows prefer music to silence and stay longer in perches triggering classical music (Bach and Vivaldi) instead of modern music (Schöenberg and Carter) (Watanabe & Nemoto 1998), and a study with grey parrots (*Psittacus erithacus*) showed that, when provided with a touch screen broadcasting either rhythmic or calm music, the birds displayed individual preferences (Péron et al. 2013). Yet, to date, musical preferences have only been studied in a very limited number of vocal learner species, thereby adding a new animal model to the data could be interesting.

The vocal learning hypothesis

For Schusterman (2008), vocal learning is an ability consisting of modifying one's vocal production regarding external auditory information. According to Watanabe et al. (2009), musical stimuli would mainly be reinforcing in species able to learn complex auditory signals. Thereby, only species capable of vocal learning, like songbirds and psittaciformes, would show musical preferences; non or limited vocal learners would only be able to discriminate musical stimuli.

Indeed, psittaciformes seem to be quite good candidates for the study of musicality: a grey parrot was able of complex musical production (Bottoni et al. 2003), budgerigars can synchronize themselves with a metronome (Hasegawa et al. 2011), and at least six psittaciformes species spontaneously entrain to a rhythm (Schachner et al. 2009) over a large range of tempi (Patel et al. 2009), one of them, a sulphur crested cockatoo *(Cacatua galerita)* even displays 14 different movements in that purpose (Keehn et al. 2019). Besides, palm cockatoos *(Probosciger aterrimus)* create tools with which they drum on hollow trunks (Wood 1984) with individual styles, sharing key components of human music (Heinsohn et al. 2017).

The current study

This study is based on a previous research conducted in the Laboratoire Ethologie Cognition Development (University Paris Nanterre, France) with two African grey parrots (P*sittacus erithacus)*, which purpose was to explore musical preferences in parrots (Péron et al. 2013). A touch screen connected to a computer was provided to the birds in the aviary. A red square broadcasting rhythmic music and a dark blue circle broadcasting calm music were located on the screen; when touching it, the birds could trigger the music. The experiment suggested that the parrots used the screen even when alone (thus without any food reward) and showed sTable individual preferences. Such a device can also improve our knowledge of animal welfare: welfare depends on individuals (McPhee and Carlstead 2010) and can be explored thanks to choice tests, which are known for revealing what the animal wants (McPhee and Carlstead 2010).

Here, we used the same device with cockatiels (*Nymphicus hollandicus*), to explore the birds' musical preferences depending on several features such as rhythmicity and the consonance / dissonance feature. Cockatiels are cacatuidae, like palm cockatoos. They also belong to the psittaciforme order, in which birds are capable of vocal learning and are known for their complex cognitive skills. Besides, their auditory sensitivity runs from 2000 to 5000 Hz (Okanoya and Dooling 1987), which broadly overlaps the human auditory sensitivity (between 2000 and 4000 Hz) (Heffner and Heffner 2006).

We thus made the following hypotheses:

(1) Because they are vocal learners, the birds would show individual musical preferences, like Java sparrows (Watanabe and Nemoto 1998) and grey parrots (Péron et al. 2013).

(2) There would be a relationship between the birds' preferences and their personality: as described before, in humans, there is a relationship between music and personality (Rentfrow and Gosling 2003; Schwartz and Fouts 2003 ; Veltri 2016).

(3) The birds would show a general preference for consonance over dissonance. Consonant intervals are usually described as smooth or pleasant, whereas dissonant intervals sound rough or unpleasant (Trainor and Heinmiller 1998). In humans, the consonance / dissonance preference appears very early (Trainor and Heinmiller 1998) and even non vocal learners like chicks (Chiandetti and Vallortigara 2011) and an infant

chimpanzee (Sugimoto et al. 2010) displayed preferences for consonance over dissonance. Besides, in a previous study, we observed that cockatiels behaved differently when listening to consonant music compared to dissonant music, suggesting that they can discriminate both (Le Covec et al. submitted).

Materials and methods

Subjects and housing conditions

This experiment was held in the Laboratoire Ethologie Cognition Développement (LECD) in Nanterre University (France), with twelve cockatiels (see Table 1 for details). The birds were housed in an indoor aviary with no window. The temperature was 23°C and the light was on from 9 am to 11 pm. Three stainless steel work benches (155*55*84 cm) were located on the right wall and there were two big perches in the middle of the room. Toys, cardboards and two triangle suspended perches were also available. Birds were feed ad libitum with, regarding the period, either seed Deli Nature or granulés ZuPreem® FruitBlend™ for large parakeet, various fruits and vegeTables, aniseed sand and water.

Table 1. Name, sex and age of the birds when each test began

Bird	Sex	Test 1	Test 2
Hermès	Male	4 years 10 months	5 years 11 months
Callisto	Female	4 years 8 months	5 years 9 months
Viviane	Female	4 years 8 months	5 years 9 months
Nephtys	Female	4 years 9 months	5 years 10 months
Seth	Male	4 years 9 months	5 years 10 months
Skadi	Female	3 years 9 months	4 years 10 months
Odin	Male	3 years 9 months	4 years 10 months
Loki	Male	3 years 9 months	4 years 10 months
Isis	Female	1 year 4 months	2 years 5 months
Éole	Male	1 year 3 months	2 years 4 months

Gaïa	Female	1 year 3 months	2 years 4 months
Morgane	Female	1 year 3 months	2 years 4 months

Test 1

A fake screen (25,5*18,5 cm) was provided to the birds (a touch screen was supposed to be used, but being non-functional we replaced it by a sheet of paper protected by a plastic). It was equipped with a small platform, on which the birds could perch. We drew on this paper screen a red square (10,5 cm*10,5 cm) and a dark blue circle (radius circle 5,6 cm), both having the same area (110 cm²) (see Figure 1.). Two music piano plays were manually triggered by an experimenter when the birds pecked a shape, both broadcasted by a speaker (Bluetooth, Ryght Exago®) hidden behind the paper screen. The paper screen was only visible when the experimenter was in the aviary, otherwise we put a cardboard in front of it.

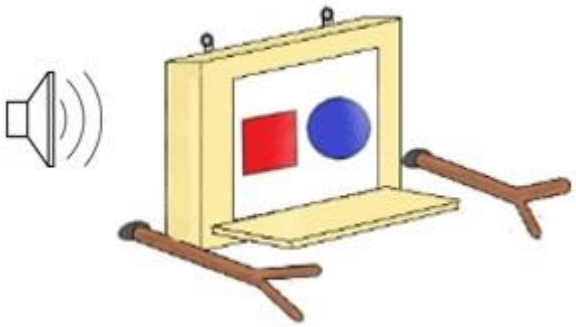

Figure 1. Experimental device

First of all, the birds were familiarized with the screen for two weeks. Millet was permanently placed on the platform and on the screen so as to encourage them to interact with the device.

Then we conducted 95 one hour sessions (2 to 4 sessions per day within six weeks). The birds were free to perch on the platform. Food was removed thirty minutes before each session, to motivate them for alimentary rewards: each time a bird touched a shape on the paper screen, the experimenter played the corresponding music and then rewarded the subject with a seed (either sunflower or millet, depending on what they were most motivated to). When there was no interaction with the screen for the first 15 minutes, the

experimenter left the aviary and came back half an hour later to try again. The two music plays broadcasted were *Rock around the clock* by Bill Haylay and his comets (rock music) and *Le roi et l'oiseau (credit movie)* by Wojciech Kilar (calm music). The training lasted from session 1 to session 28. From session 1 to session 19, the bird was rewarded as soon as he / she pecked the shape. From session 20 to session 24, we waited for 5 seconds from the moment the shape was pecked before rewarding the cockatiels, so as to be sure that they listened to the music. From session 25 to session 28, this delay was increased to 10 seconds. From session 28 to session 45, the birds were taught to wait for the end of the music (i. e. 15 seconds) before pecking another time, and were only rewarded by then (condition 1). If one bird wanted to peck while another bird had already started the music, he / she had to wait until the music stopped before pecking, otherwise he / she was not rewarded. The pass criterion for each individual was 300 pecking occurrences on the screen and at least 50 pecking occurrences on one given shape for training and condition 1: by then we considered that they had understood the device and we moved to condition 2. From session 46 to session 70, the location of shapes was exchanged to check for a position bias (condition 2). From session 70 to the end, each shape associated with a play was exchanged to check that the birds did not prefer the shape instead of the music associated to it (condition 3, see Figure 2 and Table 2 for details).

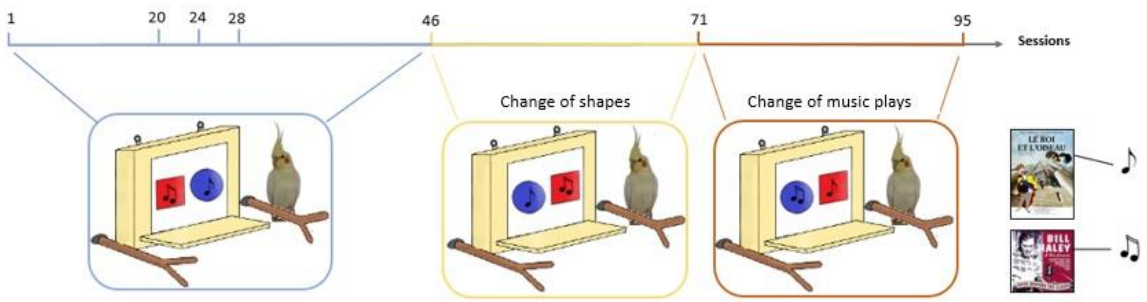

Figure 2. Changes along the sessions during the test 1

Test 2

The second experiment was conducted eleven months after the first one. This time, the birds were trained with a real touch screen (Elo 1590L 15-inch LCD). Two shapes were displayed on the screen, one orange heart and one green cross, both having the same area (110 cm^2) and broadcasting either consonant or dissonant music for 15 seconds each. Those stimuli were two different versions of the same Renaissance play, *Entrée courante* (anonymous): to create the dissonant stimuli, the original tune was electronically manipulated (using CoolEdit Pro software, by Koelsch et al. 2006), i. e. recorded simultaneously with two pitch-shifted versions, which were one tone above and a tritone below the original pitch. The birds were supposed to trigger the music by pecking the shapes with their beak, but they could not activate the music by themselves (probably because the surface of the beak in contact with the screen was not big enough); therefore the experimenter touched the shape after the birds.

We conducted 80 one hour sessions (2 to 4 sessions per day within six weeks). From session 1 to session 45, the birds were trained to use the touch screen as described previously in test 1 (i. e. increasing stepwise the duration before reward from 5 seconds to 15 seconds after the triggering of the music). From session 46 to session 58, the cockatiels were tested under the same modalities as training (condition 1). The pass criterion was 200 pecking occurrences on the screen and 50 pecking occurrences on one given shape for training and condition 1. From session 58 to session 70, the location of shapes changed (condition 2) and from the session 71 to the end, the shapes associated with each music play were exchanged, (condition 3) (see Table 2 for details).

Table 2. Types of music, locations and shapes depending on the condition for each test

Condition	Shape	Location	Style
Test 1			
1	Red square	Left	Rock
	Dark blue circle	Right	Calm
2	Red square	Right	Rock
	Dark blue circle	Left	Calm
3	Red square	Right	Calm
	Dark blue circle	Left	Rock
Test 2			
1	Orange heart	Left	Consonant
	Green cross	Right	Dissonant
2	Orange heart	Right	Consonant
	Green cross	Left	Dissonant
3	Orange heart	Right	Dissonant
	Green cross	Left	Consonant

The following details were recorded for each pecking occurrence:

- identify of the bird touching the screen
- touched shape (with the location and the music associated to it)

Personality test

In order to describe the personality of the birds, we used a personality test for parrots taken from Cussen and Mench (2014), previously adapted from a test developed by Gosling (1998) for spotted hyaenas (*Crocuta crocuta*). The revised test consisted of 43 traits that were scored for each bird from 0 (complete absence of the trait) to 7 (extreme amount of the trait). Two Raters evaluated twice within two months (score 1 and score 2) and for each bird the 43 items. One of the Raters (Rater 1) had known the birds for the last 4 years and the other (Rater 2) had just arrived in the laboratory.

Statistical analysis

All the statistical analyses were conducted with R (version 3.6.0 ; R Core Team 2019). For each test, we focused on the number of time each individual chose one given shape. First of all, for each individual, the sessions in which less than 3 pecking occurred were deleted. Then, for each condition and bird, we evaluated whether, along the sessions, the proportion of choice for a given shape remained stable (i. e. whether there was an effect of sessions or not). In that purpose, per individual and per session, we divided the number of choices for one given shape by the total number of choices (i. e. total number of pecking occurrences). The statistical unit was the number of sessions per individual, and was inferior to 20 for each condition. Then we implemented those proportions of choices in a linear model (LM, fonction : « lm », package (stats), R Core Team 2019), for which the p-value was calculated thanks to a permutation test (Monte Carlo method with 1000 permutations), using the function « PermTest » from the package (pgirmess) (Giraudoux 2018). Then, binomial tests were conducted on the total number of choices made per session and per individual (fonction: « binom.test », package (stats); R Core Team 2019). Thus, we could evaluate whether, per session, each individual chose significantly more one shape than the other. In the test 2, because the bird Nephtys had chosen the heart shape more often during the last four sessions of the condition 1, we conducted a binomial test on all her choices for the 4 last sessions. The session 8 of the condition 1 (test 2) being the only moment when she chose mostly hearts, a binomial test on the 3 last sessions (thus excluding the session 8) was also conducted, so as to check whether she had changed her preference over time.

For the personality test, we calculated first for each item of each bird the similarity intra and inter Raters, so as to check the fidelity over time and Raters. Second, based on an average of the scores which were given to the birds (i. e. for item per bird: score 1 Rater 1; score 2 Rater 1; score 1 Rater 2; score 2 Rater 2), we conducted a Principal Component Analysis (PCA). We calculated the PCA with the function « PCA », from the package (FactoMineR) (Le et al. 2008). We visualised the instrinsic values thanks to the function « barplot » from the package « grahics » (R Core team 2019). Then we drew two normed PCA with the function « plot » from the package « graphics », one for the variables with the correlation circle and the other for the individuals and the items. We only interpreted the

items and individuals which contributions were higher than the average, either for dimension 1 or 2.

Results

Test 1

Seven cockatiels interacted with the device. Among those seven, four (Gaïa, Nephtys, Éole and Seth) came regularly and reached the pass criterion (see our section “Materials and methods”).

Effect of sessions

We found an effect of sessions for Gaïa and Nephtys in condition 1, Seth and Nephtys in condition 2 and Gaïa, Nephtys and Éole in condition 3 (see Table 5 for details).

Preferences

Gaïa pecked significantly more the red square broadcasting rock in condition 1 and 2. She also pecked significantly more the dark blue circle broadcasting rock in condition 3. These results suggest that Gaïa had a preference for rock over calm music (see Figure 3 and Table 5 for details).

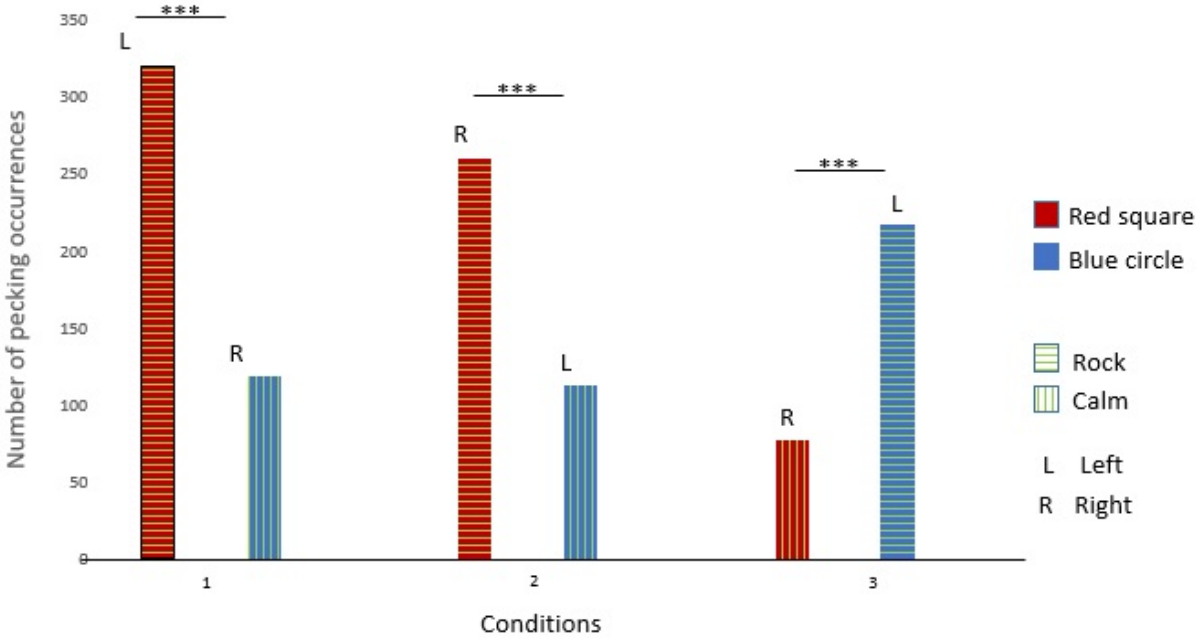

Figure 3. Gaïa's choices across the three conditions

Like Gaïa, Nephtys pecked significantly more the red square broadcasting rock in condition 1 and 2. She also pecked significantly more the dark blue circle broadcasting rock in condition 3. These results suggest that Nephtys had a preference for rock over calm music (see Figure 4 and Table 5 for details).

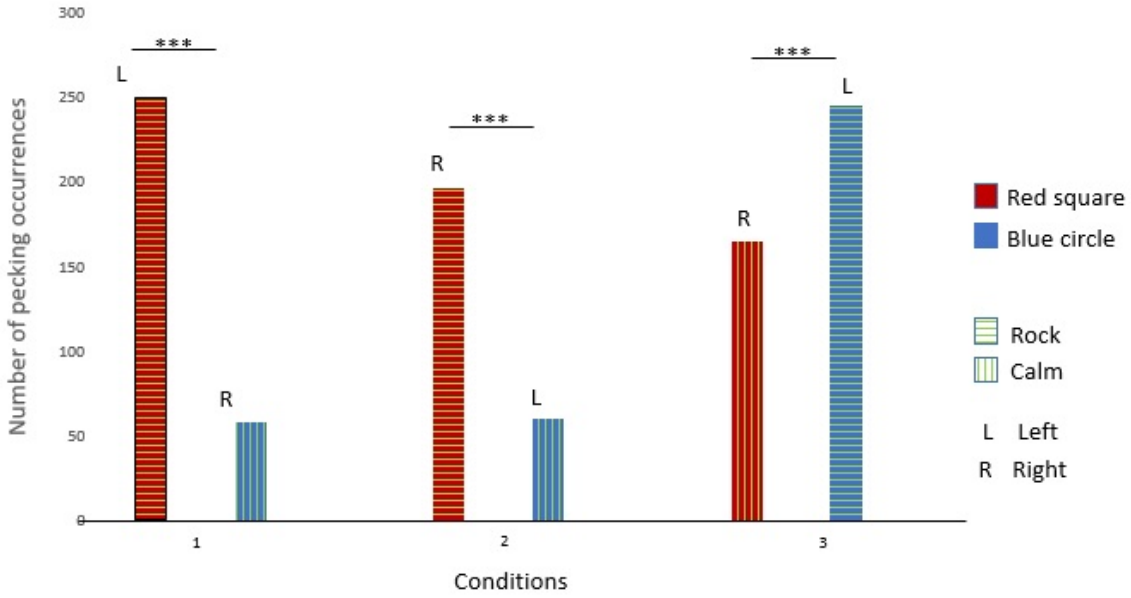

Figure 4. Nephtys's choices across the three conditions

Éole pecked significantly more the dark blue circle broadcasting calm music in condition 1 and 2. He also pecked significantly more the red square broadcasting calm music in condition 3. These results suggest that Éole had a preference for calm music over rock (see Figure 5 and Table 5 for details).

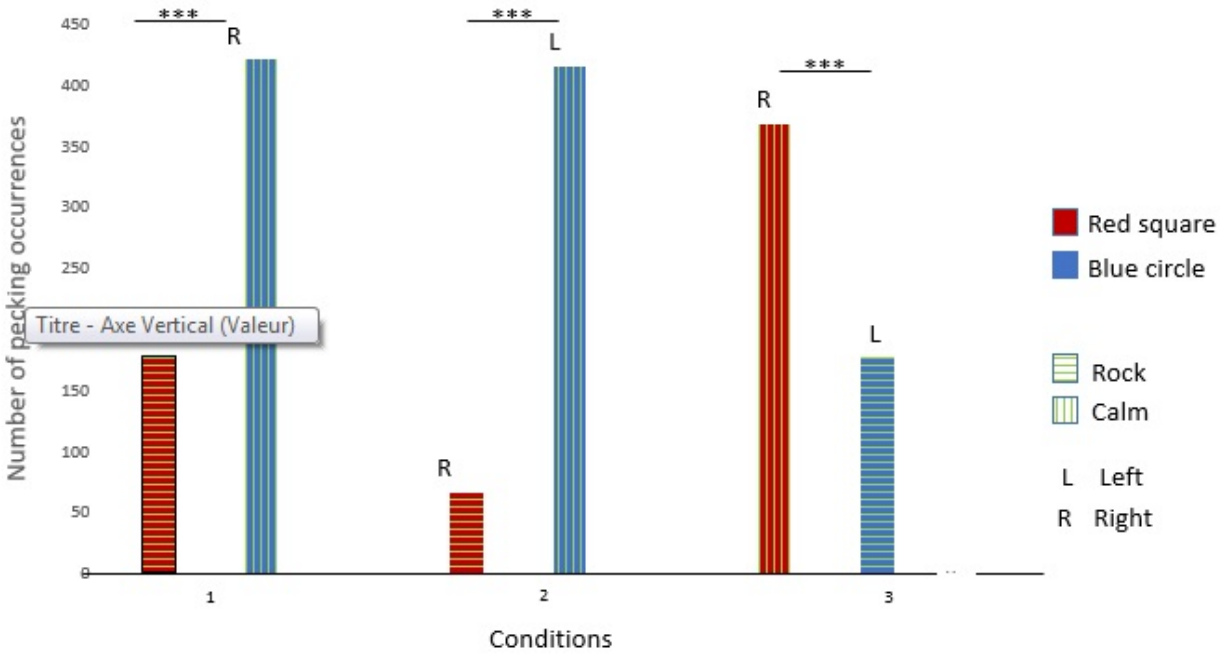

Figure 5. Éole's choices across the three conditions

Seth pecked significantly more the dark blue circle in condition 1, 2 and 3. These results suggest that Seth had a preference for the dark blue circle (see Figure 6 and Table 5 for details).

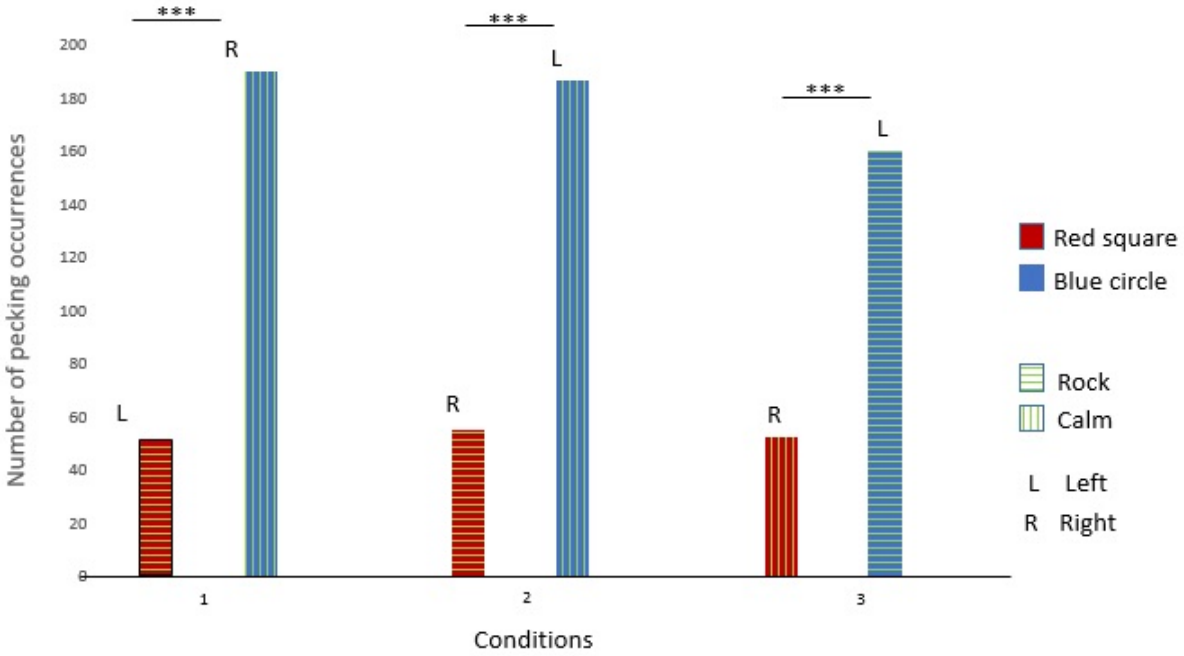

Figure 6. Seth's choices across the three conditions

Three other birds interacted with the screen (Odin, Isis and Hermès), yet they did not reach the pass criterion, thus we cannot conclude that they understood the device. Hermès only interacted a few times with the device, as a consequence, no statistical analyses were conducted on his data.

Odin pecked more the dark blue circle in condition 1 and the red square in condition 2 and 3, and Isis pecked more the red square in condition 1 and the blue circle in condition 2 and 3 (see Table 3 and 4).

Table 3. Pecking occurrences for Odin and Isis during test 1

Condition	Bird	Red square	Blue circle
1	*Odin*	49	165
1	*Isis*	71	21
2	*Odin*	50	29
2	*Isis*	27	93
3	*Odin*	15	5
2	*Isis*	3	4

Table 4. Binomial tests and LM with permutation tests depending on conditions and individuals (the significant p-values are in green) for Isis and Odin during test 1

Test 1		Binomial tests		LM with permutation test			
Condition	***Bird***	***Success***	***p-value***	***Slope (β)***	***SE***	***r²***	***p-value***
Condition 1	*Odin*	0,228972	**<0,001**	0,03719	0,03088	0,1535	0,281
Condition 1	*Isis*	0,7717391	**<0,001**	-0,04059	0,04509	0,1684	0,355
Condition 2	*Odin*	0,6329114	**0,01191**	0,11228	0,04541	0,5501	**0,046**
Condition 2	*Isis*	0,225	**<0,001**	0,01126	0,01415	0,05009	0.469
Condition 3	*Odin*	0,75	**0,02069**	-0,16667	0,06706	0,6069	0,06
Condition 3	*Isis*	0,06122449	**<0,001**	-0,02857	0,02073	0,1472	0,186

Table 5. Binomial tests and LM with permutation tests depending on conditions and individuals (the significant p-values are in green) for Seth, Gaïa, Nephtys and Eole

Test 1		Binomial tests		LM with permutation test			
Condition	***Bird***	***Success***	***p-value***	***Pente (β)***	***SE***	***r²***	***p-value***
Condition 1	*Seth*	0,212	**<0,001**	-0,012	0,008	0,121	0,165
Condition 1	*Gaïa*	0,728	**<0,001**	0,015	0,005	0,246	**0,011**
Condition 1	*Nephtys*	0,811	**<0,001**	0,010	0,004	0,333	**0,032**
Condition 1	*Eole*	0,296	**<0,001**	-0,012	0,009	0,102	0,199
Condition 2	*Seth*	0,222	**<0,001**	-0,031	0,006	0,613	**< 0,001**
Condition 2	*Gaïa*	0,699	**<0,001**	0,009	0,005	0,144	0,066
Condition 2	*Nephtys*	0,766	**<0,001**	0,023	0,006	0,456	**0,003**
Condition 2	*Eole*	0,137	**<0,001**	0,002	0,003	0,025	0,46
Condition 3	*Seth*	0,245	**<0,001**	-0,009	0,008	0,073	0,241
Condition 3	*Gaïa*	0,262	**<0,001**	-0,016	0,007	0,202	**0,028**
Condition 3	*Nephtys*	0,402	**<0,001**	-0,031	0,007	0,461	**< 0,001**
Condition 3	*Eole*	0,675	**<0,001**	0,013	0,004	0,295	**0,001**

Test 2		Binomial tests		LM with permutation test			
Condition	***Bird***	***Success***	***p-value***	***Slope (β)***	***SE***	***r^2***	***p-value***
Condition 1	*Nephtys*	0,242	**<0,001**	-0,053	0,014	0,616	**0,002**
Condition 1	*Isis*	0,832	**<0,001**	0,075	0,031	0,427	**0,047**
Condition 2	*Nephtys*	0,008	**<0,001**	0,006	0,004	0,268	0,212
Condition 2	*Isis*	0,128	**<0,001**	0,008	0,014	0,047	0,583
Condition 3	*Nephtys*	0,039	**<0,001**	-0,009	0,013	0,071	0,577
Condition 3	*Isis*	0,163	**<0,001**	-0,001	0,031	$3,069 \times 10^{05}$	0,987

Test 2

Two cockatiels (Nephtys and Isis) interacted regularly with the device and reached the pass criterion (see our section “Materials and methods”).

Effect of sessions

We found an effect of sessions for Nephtys and Isis in condition 1 (see Table 5 for details).

Preferences

Nephtys pecked significantly more the green cross in condition 1, 2 and 3. Those results suggest that Nephtys had a preference for the green cross (see Figure 7 and Table 5 for details).

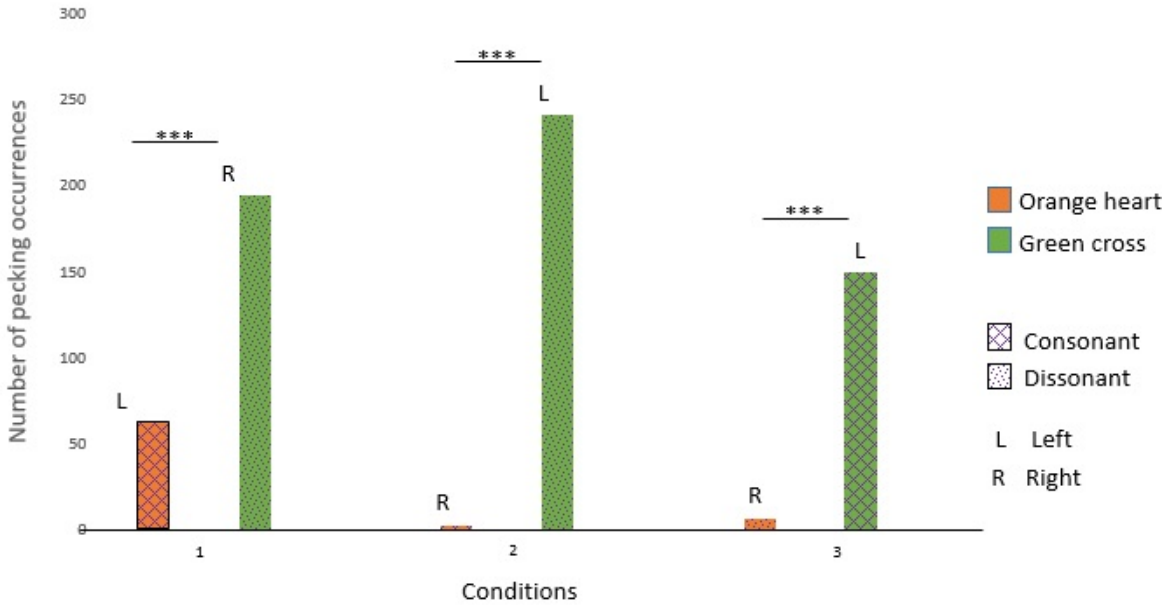

Figure 7. Nephtys's choices across the three conditions

Isis pecked significantly more the orange heart in condition 1 and the green cross in condition 2 and 3. Those results suggest that Isis had a preference for the left side (see Figure 8 and Table 5 for details).

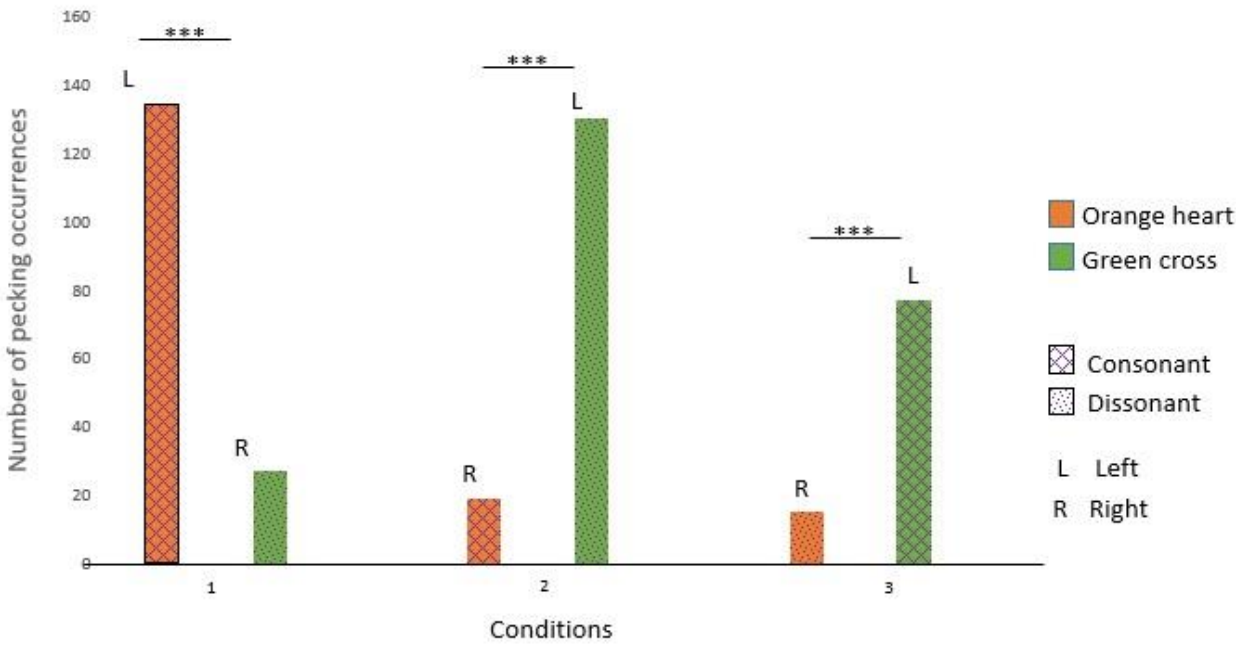

Figure 8. Isis's choices across the three conditions

Personality test

The similarity percentages intra and inter Raters were the following ones: Rater 1, scores 1 and 2 = 88%; Rater 2, scores 1 and 2 = 82%; score 1, Raters 1 and 2 = 78% and score 2, Raters 1 and 2 = 78%. Although to date, there is no official fidelity threshold, fidelity is considered correct above 0,70 and adequate above 0,80 (Bernaud 2014, quoted by Charlier 2018).

PCA results

71,6 % of the variance of the PCA was explained by the first two axes. Due to their low contribution to the dimension 1 or 2, the items “Insecure”, “Protective”, “Submissive”, “Territorial” and “Vigilant” and the birds Isis, Loki, Morgane, Odin and Hermès were not interpreted (see Table 6 and 7).

Table 6. Items contribution to the dimension 1 and 2 (in red: contribution too low to be interpreted)

Item	Dim.1	Dim.2
Active	4,2571	0,3578
Sociable	2,3897	2,5116
Aggressive	3,2076	1,5303
Daring	4,3238	0,3338
Bullying	3,2375	0,4672
Calm	1,6816	3,6217
Cautious	3,5259	0,8294
Confident	4,0756	0,8149
Curious	4,433	0,0025
Depressed	3,813	1,4302
Direct	3,5124	0,1886
Eccentric	0,5239	5,0911
ExciTable	2,6798	2,1066
Fearful	2,4305	0,2364
Feisty	0,4439	6,8596
Flexible	0,5537	5,8129
Gentle	0,5924	6,8323
Independent	1,4352	3,5032
Inept	2,0834	2,962
Intelligent	4,3799	0,1326
Insecure	1,3007	1,5935
IrriTable	0,778	6,5268
Jealous	3,1307	0,0815
Lazy	4,1334	0,0634
Nervous	0,0836	6,1735

Nurturant	0,5558	5,1307
Opportunistic	4,1792	0,3723
Persistent	3,597	0,4318
Playful	3,646	0,5282
Protective	1,1421	1,1039
Selfish	0,184	3,6688
Slow	2,9957	0,3068
Solitary	1,4079	4,0208
Submissive	1,9722	0,0005
Tame	4,3662	0,1679
Tense	1,6981	4,4806
Territorial	1,9801	1,0601
Timid	3,618	0,8639
Tolerant	0,0027	7,774
Understanding	0,1578	4,0209
Unemotional	3,276	0,8703
Vigilant	1,4294	0,1344
Warm	0,7853	5,0005

Table 7. Birds' contribution to the dimension 1 and 2 (in red: contribution too low to be interpreted)

Bird	Dim.1	Dim.2
Bahloo	0,0009	59,506
Seth	12,564	0,0726
Nephtys	6,8469	2,6198
Isis	0,1244	0,2743
Callisto	22,086	5,0473
Loki	0,5939	3,6531
Morgane	3,0414	0,8754
Gaïa	0,7599	15,734
Éole	28,7207	5,4984
Viviane	6,6112	1,0531
Odin	0,9858	0,8997
Skadi	17,2144	0,3479
Hermès	0,4504	4,4183

According to the PCA, among the birds who displayed musical preferences, Gaïa, who preferred rock over calm music, is mostly described by the items "Flexible", "Warm", "Tolerant" and "Nurturant" and Nephtys, who also prefers rock over calm music, is mostly described by the items "Tame", "Daring" "Direct", "Opportunistic", "Playful", "Confident" and "Intelligent". Éole, who prefers calm music over rock, is mostly described by the items "Aggressive", "Persistent", "Bullying" and "Active".

Among the birds who interacted with the device without showing musical preferences, Seth is the only one who can be interpreted, and he is mostly described by the items « Jealous», « Curious», "Tame", "Daring", "Opportunistic", "Direct" and "Intelligent" (see Figure 9 and 10).

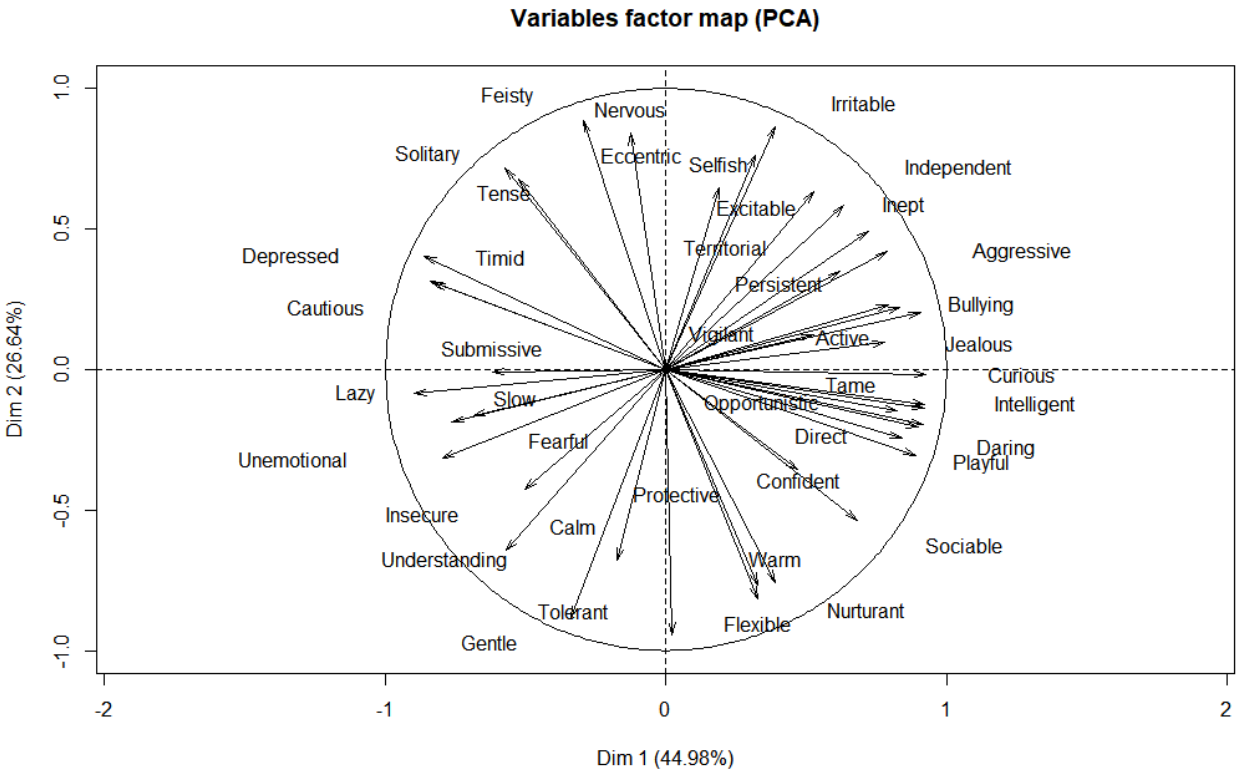

Figure 9. Representation of the items regarding the PCA and the correlation circle

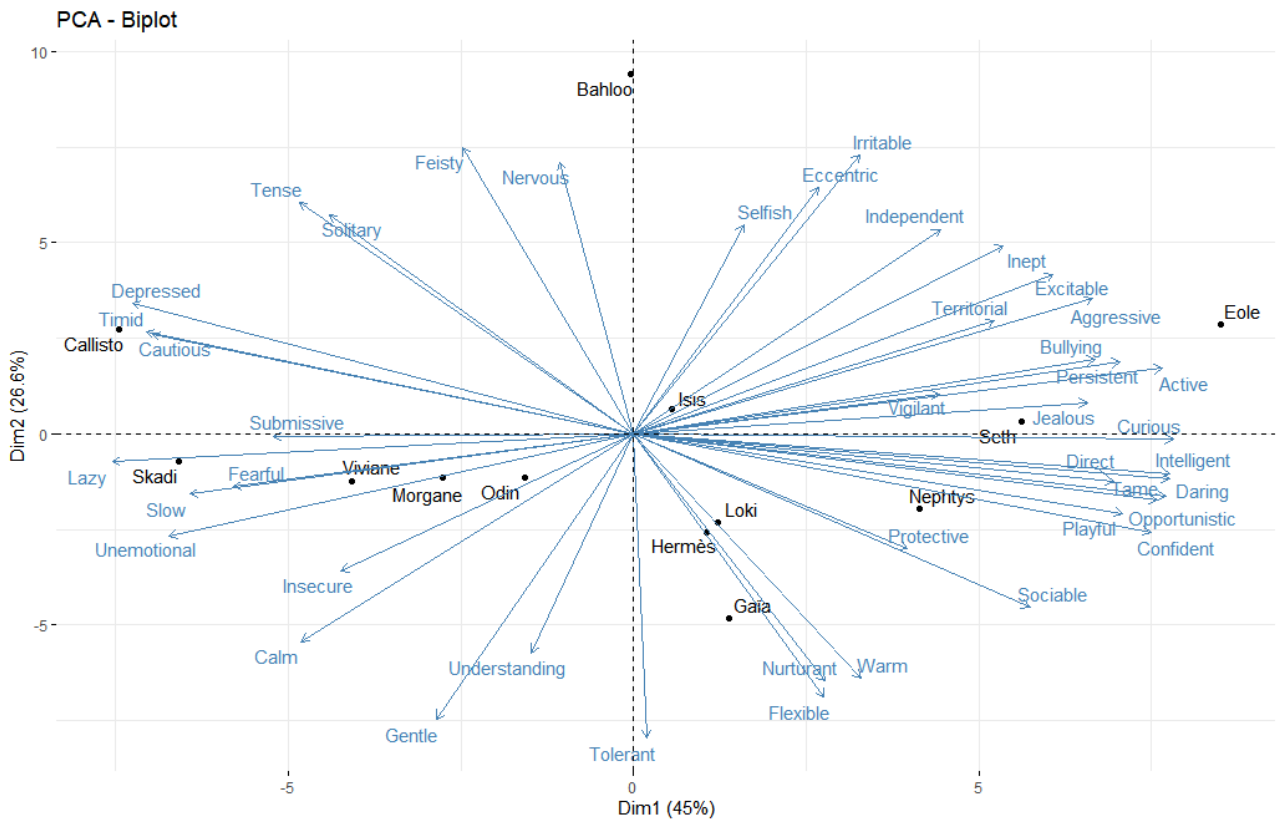

Figure 10. Representation of the items and the birds regarding the PCA

Discussion

Musical preferences

Three cockatiels displayed individual musical preferences: Gaïa and Nephtys, two females, preferred rock over calm music and Éole, a male, preferred calm music over rock. These results support the hypothesis according to which vocal learners would be sensitive to musicality: musical preferences have already been shown in Java sparrows (Watanabe and Nemoto 1998) and grey parrots (Péron et al. 2013). In grey parrots, those preferences were also different according to the individuals, thereby those positive results confirm that psittaciformes are good candidates for the study of musicality in non-human animals.

In most of cases, the effect of sessions happened during the beginning of one given condition, and can be explained by the time the birds needed to understand a new configuration of shapes and/or music plays. It is especially true for the condition 3 of the test 1: Gaïa, Nephtys and Éole probably needed some trials to get that the music they preferred was not broadcasted by the same shape as before, and to adjust their behaviour. Two other effects of sessions (for Nephtys during the condition 1 of the test 1 and for Isis during the condition 1 of the test 2) could be related to preferences still being determined: both happened during condition 1, suggesting that the birds might not have established their choice by that time. Yet this seems unlikely for Isis, since she had already shown a preference for the left side during the test 1 and may have just repeated it during test 2. Another explanation would be that they had not understood yet which shape was associated with which type of music. Two other cases (for Gaïa during condition 1 of the test 1 and for Nephtys during condition 1 of the test 2) are related to a very few atypical sessions displaying extreme values, for which we have no explanation.

Among the other birds who interacted with the device but did not show musical preferences, Odin pecked more on the right side and Isis pecked more on the left side; this may be due to a side preference and/or to a lack of understanding of the device, as they did not reach our pass criterion.

Indifference to the consonance / dissonance feature

Surprisingly, for the two subjects who interacted with the device during test 2, our results did not show any preference for consonance over dissonance. Indeed, Isis seems to prefer the left side over the right side, more than the music associated to it. As for Nephtys, in spite of preferring rock over calm music in the test 1, in the test 2 she seems to prefer the green cross across the three conditions, and thus to be indifferent to the consonance / dissonance feature.

Those findings are inconsistent with a universal preference for consonance over dissonance. As it happens, notwithstanding studies supporting a biological preference for consonance in mankind (Trainor and Heinmiller 1998) and some primates (Sugimoto et al. 2010), contrasted results have been noticed since. For example 6 month-old infants exposed either to consonant or dissonant music listen more to the type of music they have been exposed to, whether it is consonant or dissonant (Plantinga and Trehub 2014) and members of the Tsimane' Amazonian tribe, in spite of being able to discriminate consonance from dissonance, do not prefer one type of music over the other (McDermott et al. 2016). This suggests that the preference for consonant music over dissonant music would also be related to the exposure to such music, and thereby that experience would play a crucial part in this taste. In a previous study, our cockatiels showed different behaviour when exposed to consonant *versus* dissonant music (Le Covec et al., submitted). In the current study, the musical stimuli we used were the same as in the previous one, therefore the birds were exposed to both types of music before this experiment and may be habituated to them.

Individual preferences and personality

In humans, personality can be related to musical tastes and give us information about the reasons why people develop preferences for music (Veltri 2016). Here, because only seven birds interacted with the device, and among them only three showed preferences, it is very difficult to draw any conclusion about the relationship between personality, musical preferences and interactions with the apparatus. Gaïa and Nephtys, who preferred rock over calm music, do not seem to share any personality item. Éole, who prefers calm music over rock, is rather described by the items "Aggressive", "Persistent", "Bullying" and "Active". In

studies conducted on humans, on the contrary, similar features such as thrill seeking were related to preferences for rock (Delsing et al. 2008) and to a greater sensibility for the structure of music (i. e. tempo and rhythm) (Veltri 2016). Yet on a similar study in grey parrots, the more aggressive and energetic bird preferred calm music too (whether it was the other way round for the other bird; Péron et al. 2013). It is also interesting to note that Seth and Nephtys share several personality items such “Tame”, “Direct”, “Opportunistic”, and “Intelligent”. As it happens, Nephtys and Seth are siblings, were both hand-reared and are mates, several elements that could explain why they have some personality features in common. Yet, since we only have very few data, we must be very cautious about those results: the reasons why, among all the birds that showed interest in the experiment, some displayed preferences and others not and why these preferences vary among individuals remain unclear. Regarding Isis, Odin and Seth, it seems very unlikely that this would be due to an incapability to understand the apparatus, since previous experiments showed that they can learn tasks when rewarded. The fact that they did not show musical preferences could be related to a lack of motivation and / or an important position bias. It is also possible that our stimuli were not relevant for all of the birds, and that some of them disliked what we provided. This study is the very first to explore the relationship between musical preferences and personality in non-human animals; other researches would need to be conducted to examine the topic further.

Limitations and prospects for further research

Unfortunately, this study was limited by the device, which did not work as expected. The touch screen had been selected because the grey parrots could successfully use it. Nevertheless, with the cockatiels, either the screen would not activate at all, either the sound would not trigger. This could be due to the smaller size of their beak, which did not press enough surface. Thereby we could not test whether they would have used the apparatus in the absence of the experimenter, which makes it impossible to conclude whether they pecked preferentially to get the music or the food reward. Thus, it would be interesting to provide a device adapted to their specificities, like in Gupfinger & Kaltenbrunner experiment (2017), in which grey parrots can interact with an apparatus consisting of rope perches with captors, triggering music when the birds perch on it.

Reproducing our two tests after a delay (of some months or even years) could also give us information about the stability of the birds' choices: not only would it be interesting for our knowledge, but this would also be important for animal welfare, given that if musical tastes change over time, it would be necessary to adjust sound enrichment depending on their current preferences.

Vocal learning: a continuum?

Cockatiels seem sensitive to music. Coupled to other data we obtained, such as the positive influence of music on their interactive behaviour (Le Covec et al. submitted) and an interest in producing sounds and drumming (Le Covec et al. 2019), those results support Watanabe et al. hypothesis (2009), which suggests that musical stimuli are mostly reinforcing in species that are capable of vocal learning.

Yet, over the past few years, less categorical assumptions have been made, arguing for a gradual continuum instead of an absolute jump. First of all, vocal learning might not be a dichotomous feature, but a continuum ranging from non-vocal learners and limited vocal learners to complex vocal learners (Arriaga and Jarvis 2013). Besides, several non-vocal learners display a certain sensitivity to music, more specifically a positive effect of music has been evidenced in zoo-housed western lowland gorillas (*Western lowland gorillas*) (Wells et al. 2006) and captive dogs (*Canis lupus familiaris*) (Kogan et al. 2012; Wells et al., 2002; Boone and Quelch 2003). Other non-vocal learners show musical preferences, as is the case of degus, which have highly developed communication and prefer Chilean folk music to Western music and silence (Watanabe et al. 2018) or mice, which can develop musical preferences if they are exposed to music during a critical period (between day 15 and day 25 after birth) (Yang et al. 2012). Therefore, vocal learning is probably not the only factor linked to musicality in animals.

Conclusion

Our results show that some cockatiels display individual musical preferences, supporting the idea that, as vocal learners, they are sensitive to music.

This data could also help to improve animal welfare and pave the way for new researches: a motivational theory concerning captive animal welfare suggests that in captive environments, the lack of quantity and diversity of stimuli often results in sensory deprivation, which would induce poor welfare; enriching the senses via, inter alia, auditory environmental complexity would reduce negative behaviour (McPhee and Carlstead 2010). This is why it is important to study independently, as we did, several features of musicality, in order to adapt at best the musical broadcast or choices provided for enrichment to captive animals. The study of a possible relationship between personality and musical preferences would also help to adapt the type of musical enrichments to the individuals.

Moreover, personal observations showed us that, when we drum against a metal perch, the cockatiels raise their crest and calm down; therefore studying more precisely rhythm preferences and influences in those birds could provide further information about their musical sensitivity.

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2.2. Chez les corbeaux à gros becs

Musical preferences and influence of music on behaviour in jungle crows

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Abstract

Music may be one of the oldest forms of art and its appreciation is thought to be universal. More specifically, vocal learners like passeriformes or psittaciformes display several musical abilities, and seem to be quite good candidates for the study of music in non-human animals. In this experiment, we explored the discriminating and reinforcing levels of music (i. e. respectively the ability to discriminate several musical stimuli and to feel pleasure when exposed to music) in seven jungle crows. The birds were tested individually with four types of music, a white noise, or without playback; we recorded their spontaneous behaviour and the time spent next to the speaker depending on the type of stimuli. The results showed very few effects of music on behaviour and no effect of music on the time spent next to the speaker; yet, due to our small sample and difficult experimental conditions, we cannot conclude about the discriminating and reinforcing properties of music in those birds. Nevertheless, the crows stayed away from the speaker when hearing the white noise, which suggests that they disliked it. Further studies should be conducted in that field.

Keywords: bird; corvid; jungle crow; music discrimination; music reinforcement; musical preferences

Introduction

The earliest musical instrument ever discovered is a bone pipe and would have been created 45, 000 years ago (Tuniz et al., 2012). Thereby, music is likely to be one of the oldest forms of arts and would have a long history; it exists in every human culture (Merriam and Merriam, 1964), including people with traditional lifestyles (Watanabe et al., 2009). Its appreciation is thought to be universal (Watanabe et al., 2009; McDermott and Hauser, 2005; Sugimoto et al., 2010).

Music in non-human animals

Although music is often considered as a human specificity (see for example D'Azevedo, 1958; Godt, 2005; Dutton, 2006), even Darwin (1871) suggested that the song of birds sounds beautiful to us because we share a "sense of beauty" with other species.

Nevertheless, there is no consensus about the definition of music, it is therefore complicated to study in non-human animals. Yet we know that we share with other mammals some perceptive mechanisms that have a very long evolutionary history and would stand at the basis of music (Fitch 2006): when perceiving a melody for example, humans and non-human animals would partly rely on the pitch (Hulse et al.,1992).

The concept of musicality, described by Hoeschele et al. (2015) as "the capacity that makes it possible for us to perceive, appreciate and produce music", is broader than the idea of music, and might thus be easier to explore. Otsuka et al. (2009) explain that musicality can be studied via two levels: (1) the discriminating level, i. e. the ability to discriminate music, and (2) the reinforcing level, i. e. the ability to perceive music as a pleasant stimulus.

Musicality in non-human primates

Musicality has already been explored in apes and monkeys, phylogenetically very close to humans, with contrasted results. Macaques (*Macaca mulatta) (*Zarcoet al., 2009) and one chimpanzee (Hattori et al., 2013) can synchronize themselves with an external sound; tamarins and marmosets prefer music with slow tempi over fast ones (McDermott and

Hauser, 2007), whereas chimpanzees prefer African or Indian music over silence (Mingle et al., 2014); an infant chimpanzee displayed a preference too, for consonance over dissonance (Sugimoto, 2010). Drumming was also observed in several wild male chimpanzees (Babiszewska et al., 2014) as well as in a captive one, Barney, whose performance shared several features of human musical drumming (Dufour et al., 2015). Yet, a complementary study to Barney's case did not find any convincing performance in other chimpanzees (Dufour et al., 2017), and it is worth noting that chimpanzee and monkeys need a very long training (until one year) before synchronizing to a pulse (Zarco et al., 2009; Hattori et al., 2013) and do it with more time variability and less accuracy than humans (Zarco, 2009); as for marmosets, tamarins (McDermott and Hauser, 2007) and orang-utans (*Pongo abelii*) (Ritvo and McDonald, 2016), they prefer silence over music.

The vocal learning hypothesis

Vocal learning is the ability to modify one's vocal production depending on external auditory information (Schusterman, 2008). According to Watanabe et al. (2009), this feature would have an influence on musical sensitivity, i.e. a species that does not learn complex auditory simulation during its ontogenesis would be able to discriminate different kinds of music, but would not display any reinforcing effect of music.

Apes and monkeys are limited vocal learners (Janik and Slater, 1997). In contrast, vocal learning is likely to have evolved convergently in at least three groups of birds: passeriformes (songbirds), psittaciformes (parrots) and hummingbirds (Fitch, 2006). Passeriformes, psittaciformes and hummingbirds would be, thereby, quite good candidates for the study of musicality.

The song of birds is often considered as "music": as a matter of fact, ethologists and musicologists both qualify some avian vocalizations of "song" (Fitch, 2006). Indeed, when singing, many passeriformes would share precise rules, especially those triggering emotions, with human music (Rothenberg et al., 2014); other passeriformes display some musical aptitudes, such as common bullfinches, (*Pyrrhula pyrrhula*), who can learn melodies taught by humans and whistle musical plays, but also synchronously anticipate the end of those

plays (Nicolai et al., 2013). Birds' temporal resolution is even more precise than ours (Dooling et al., 2002).

As for psittaciformes, they also show numerous musical abilities: budgerigars (*Melopsittacus undulatus*) synchronize themselves with a metronome (Hasegawa et al. 2011), six psittaciforme species (Schachner et al., 2009) can spontaneously keep the beat while they dance (Fitch, 2009) through a large range of tempi (Patel et al, 2009), palm cockatoos (*Probosciger aterrimus*) create tools with which they drum on hollow trunks (Wood, 1984) and produce regular beats, sharing key features of human instrumental music (Heinsohn et al., 2017) and Theo, a grey parrot (*Psittacus erithacus*) showed that she was able to sing in response to a musical stimulus and to generalize the rules of the music she heard to other notes (Bottoni et al., 2003).

More specifically, the two levels of musicality studied by Otsuka et al. (2009) have already been evidenced in several passeriforme and psittaciforme species. Starlings (Hulse et al., 1984), jackdaws (*Corvus monedula*) (Reinert, 1965), zebra finches (*Taeniopygia guttata*) and budgerigars (*Melopsittacus undulatus*) (ten Cate et al., 2016) can discriminate rhythms and pulses, and common starlings (*Sturnus vulgaris*) (Hulse et al., 1995) and Java sparrows (*Lonchura oryzivora*) (Watanabe and Nemoto, 1998) can discriminate music; we also noticed that cockatiels (*Nymphicus hollandicus*) could discriminate consonance from dissonance (Le Covec et al., submitted). Music reinforcement has been shown in Java sparrows, who stay longer in perches triggering classical music (Bach and Vivaldi) instead of modern music (Schönberg and Carter) (Watanabe and Nemoto, 1998), and a study with grey parrots evidenced that the birds had individual musical preferences and pecked a touch screen so as to broadcast the music they wanted to hear (either rhythmic or calm music) (Péron et al., 2013). Music has also been shown to alter behaviour in starlings (Robbins and Margulis, 2016) and we evidenced a positive effect of music on social interactions and individual musical preferences in cockatiels (Le Covec et al., submitted).

Thereby, musicality and vocal learning could be analogous traits, i. e. similar features that are not present in a common ancestor but evolved independently in two lineages (Fitch, 2006).

The current study

The aim of this experiment is to study the discriminative and the reinforcing levels of music in jungle crows by broadcasting them several types of music.

Jungle crows are corvids from South-Est Asia and belong to the passeriforme order. They are gregarious, inhabit urban zones and feed in garbages (Matsubara, 2003). Jungle crows are capable of vocal learning. Whereas a few studies have already been conducted on musical abilities in parrots, to date, it has never been the case for corvids, although both psittaciformes' and corvids' cognitive abilities are often compared (for a comprehensive review, see Lambert et al., 2019), especially because their cognitive abilities challenge apes' (Emery, 2006).

Thus, we wish to test for Otsuka's et al. (2009) musicality levels in a corvid species and make the following hypotheses:

(1) The jungle crows will be able to discriminate several types of music, as is the case of other passeriformes, and will thus display different behaviour depending on what they hear.

(2) Music will have a reinforcing effect on jungle crows, who will display more positive and less stereotypic behaviour in music than in silence or white noise, and will show musical preferences, like other vocal learners. More specifically, we suggest that the jungle crows will prefer Japanese music to other types of music, because this species lives in Japan. In a study with degus (*Octodon degus*), which live in South America, Watanabe et al. (2018) evidenced a preference for Chilean folk music over Western music and silence. They hypothesised that the soundscape of the area where lived native people may have influenced their music, and may also trigger preferences in non-human animals, which would prefer the particular acoustic stimuli based on the soundscape they lived in.

Materials and Methods

Ethic statement

The jungle crows were caught in the wild under permission by the Japan Ministry of the Environment (authorization number #2025575).

Subjects and housing conditions

This study was held in the Centre for advanced Research on Logic and Sensibility, in the department of Psychology of Keio University (Japan), with seven jungle crows, four females and three males. All the crows had been caught in the wild after becoming sub-adults (about six-months-old), in Tokyo and neighbour areas, and then housed in individual cages (76cm*48cm*54cm) in the laboratory. They were two- to three-years-old when they were tested. The light was on from 8 am to 11 pm.

Stimuli

The stimuli consisted of four music plays (see table 1) and a white noise, each one lasting three minutes and broadcasted continuously five times (i. e. for fifteen minutes). The volume was adjusted to be similar for all the stimuli.

Table 1: description of the stimuli

Type of music	Stimulus
Classical	Glen Gould - Bach: The Goldberg Variations, BWV 988 (1955 mono) - Gould Remastered Aria - Variation 1 a 1 Clav. - Variation 2 a 1 Clav.
Modern	Glen Gould - Glen Gould plays Schoenberg: Klavierstücke opp.11, 19, 23, 33; Piano Suite op. 25; Piano concerto op . 42; Fantasy for Violin & P No. 1, Mäßige Viertel
Japanese 1	Festival music - Unknown composer – played by Kanda Bayashi
Japanese 2	Traditional folk music - Unknown composer – played by Tsugaru Jongara Busiand Takahashi Chikuzan
White noise	White noise

Study design

Every morning, one bird was taken to an outdoor aviary (2,7 m * 1,5 m * 1,6 m, see Figure 1.). All the testing sessions were conducted in this outdoor aviary and filmed so as to be analysed later. The birds already knew the aviary, since they had been placed there before the experiment for bathing and social interactions with each other. Food and water were available on the floor of the aviary. The birds were tested in six conditions: classical music, modern music, Japanese music 1, Japanese music 2, white noise and silence, using the stimuli described in table 1 (nothing was played for the silence condition). The stimuli were broadcasted with a Bluetooth speaker. In order to be sure that the birds getting closer to the speaker would be attracted by the sound broadcasted, and not by the speaker itself, we put two speakers next to the aviary, a playing one broadcasting the stimulus and a silent one broadcasting nothing. Both speakers were located on two sides of mesh walls (because of the two walls against which was located the aviary, the speakers could not be face to face). On the morning, the playing speaker was located on one side of the aviary, on the afternoon it was located on the other side, and it was reversed the next day. Three perches were set in the aviary at equal distance from another. The closest perch to the playing speaker was named “zone 1”, the furthest one (i. e. closer to the silent speaker) “zone 3” and the perch in between “zone 2”. As a consequence, the perch located in the middle was always “zone 2”,

but because the playing and the silent speakers were exchanged once a day, the perches located in the back and in the front of the aviary were either “zone 1” or “zone 3”, depending on where were the playing and the silent speakers. (see Figure 2.). Three other areas were considered: the floor of the aviary (“floor”), the front of the aviary, in which there was a little edge (“edge”) and the grid, were the crows sometimes clang to (“grid”).

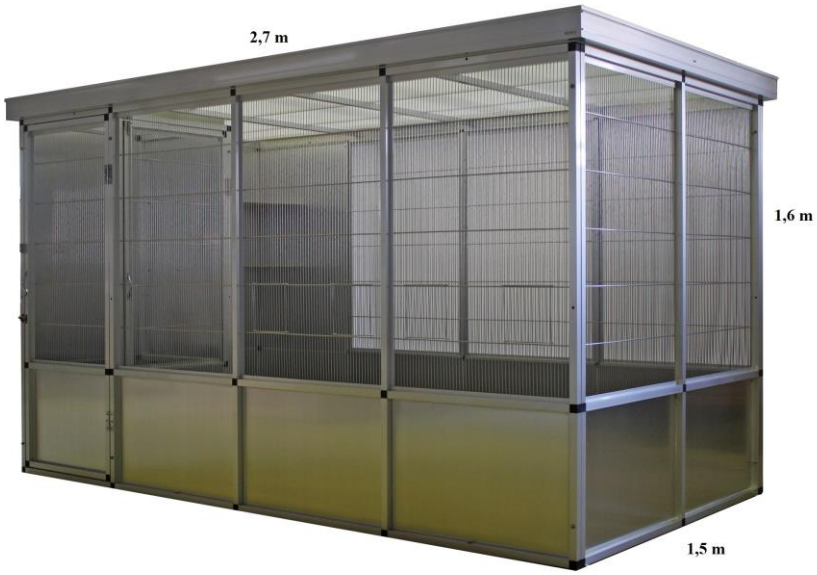

Figure 1. Aviary in which the experiment was conducted

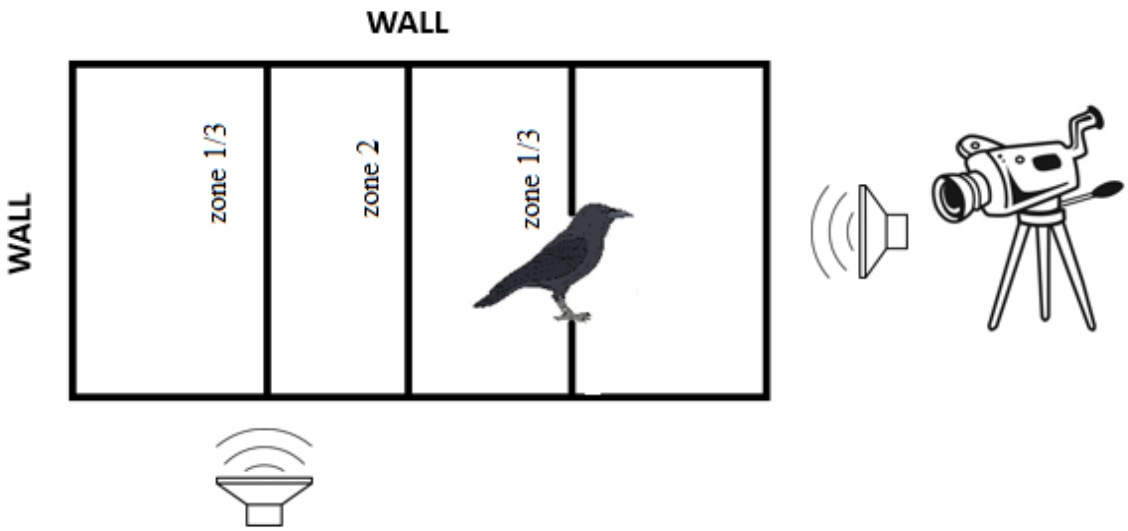

Figure 2. Illustration of the experimental device

During the testing, the subjects' sex was alternated (e. g. day 1 a male, day 2 a female, day 3 a male and so on). All the five stimuli were broadcasted two times a day: once in the morning and once in the afternoon, within the same order per day. Each stimulus was separated from the following one by fifteen minutes of silence, so as to determine a baseline behaviour (see Table 2**)**. One hour and forty-five minutes separated the morning period and the afternoon period. The order of the stimuli was randomized from one day to another. All the stimuli were manually started and stopped by the same experimenter, non-familiarized with the birds. The experimenter was not present with the tested bird during broadcast. Each bird was tested for at least one day (see table 3), i. e. heard each stimuli for 30 minutes and was filmed during two hours and fortyfive minutes in the morning and two hours and forty-five minutes in the afternoon. When all the birds were tested for one day each, we conducted descriptive analyses and tested again three females (see table 3), who seemed to show preferences, for one more day each, in order to see whether their preferences were consistent in time. In total, those three females heard each stimulus for one hour and were filmed during five hours and thirty minutes within two mornings and five hours and thirty minutes within two afternoons, that is for eleven hours within two days.

Table 2: Planning of broadcasting

Morning		**Afternoon**	
9h00	*Silence*	***13h***	*Silence*
9h15	Stimulus 1	***13h15***	Stimulus 1
9h30	*Silence*	***13h30***	*Silence*
9h45	Stimulus 2	***13h45***	Stimulus 2
10h	*Silence*	***14h***	*Silence*
10h15	Stimulus 3	***14h15***	Stimulus 3
10h30	*Silence*	***14h30***	*Silence*
10h45	Stimulus 4	***14h45***	Stimulus 4
11h	*silence*	***15h***	*Silence*
11h15	Stimulus 5	***15h15***	Stimulus 5
11h30	*silence*	***15h30***	*silence*

Table 3: Order of the tests

Day	Bird
30/11/2017	27
01/12/2017	fY
02/12/2017	28
03/12/2017	PP
04/12/2017	RM
05/12/2017	vf
06/12/2017	*FA*
07/12/2017	cc
14/12/2017	fY
15/12/2017	vf
16/12/2017	cc

Coding

All the videos were coded by the same experimenter. Each video was coded two times by focal sampling.

First of all, we recorded the time spent by the birds in each zone of the aviary.

Second, we recorded the birds' behaviour as described in table 4.

Table: 4 behaviour recorded for the birds

Behaviour	Description
Flapping wings	Bird flapping his/her wings when perching
Climb grid	Bird jumping on the grid
Open beak	Bird opening widely his/her beak
Peck grid	Bird striking the grid with his / her beak
Peck perch	Bird striking the perch with his / her beak
Preening	Bird preening
Shaking feathers	Bird shaking his/her feathers
Squawk	Bird squawking
Head upside down	Bird lowering his/her head between his/her legs

Statistical analysis

First, we tested whether the sound stimuli (classic, modern, Japanese 1, Japanese 2, white noise or silence) influenced spontaneous behaviour (flapping wings, climb grid, open beak, peck grid, peck perch, preening, shaking feathers, squawk, head upside down), all birds included. Then, we tested whether the music influenced the time spent in one given zone (zone 1, zone 2 or zone 3), all birds included. The areas “floor”, edge” and “grid” were not included in the statistical analysis, being irrelevant for the current study. Each dependant variable was analysed in a distinct linear mixed model (LMM) using the R program R Core Team 2019 and the add-on package lme4 (Bates et al., 2014). We included as fixed effects moments (morning or afternoon), configuration (1 or 2) and zone when relevant (i. e. when testing the influence of sound stimuli on behaviour), such as the possible interactions between those effects. The identity of the birds was added as a random effect. We also tested, for each bird individually, whether the music influenced the time spent in one given zone (zone 1, zone 2 or zone 3). Per bird, each independent variable was analysed in a distinct linear model (LM) using the R program R Core Team 2019 and the add-on package stats. We included moment, configuration and day (1 or 2) when relevant (i. e. for the three birds that passed the test for two days instead of one) as fixed effects, such as the possible interactions between those effects. To maximize the model likelihood, when an interaction was not significant, we deleted it and repeated the process without it. We used PermTest using the add-on package pgirmess (Giraudoux, 2018) to obtain p-values. In addition, we used post-hoc Tukey tests (Tukey, 1949) to perform pairwise comparisons between the factors.

Results

Effect of music on behaviour – all individuals included

We did not find any effect of music on the behaviour “flapping wings”, yet there is a significant effect of the interaction music*moment and music*configuration on this behaviour.

We did not find any effect of music on the behaviour “climb grid”, yet there is a significant effect of the zone and of configuration on this behaviour.

We found a significant effect of music on the behaviour “open beak”, yet we did not find any significant differences after pairwise comparisons and Bonferroni corrections. We found a significant effect of the zone on this behaviour.

We did not find any significant effect of music on the behaviour “peck grid”.

We did not find any significant effect (but a tendency, 0.060) of music on the behaviour “peck perch”. We found a significant effect of the zone and of the interaction music*configuration of this behaviour.

We did not find any significant effect of music on the behaviour “preening”, yet there is a significant effect of the zone on this behaviour.

We found a significant effect of music on the behaviour “shaking feathers”: the birds shake more their feathers when hearing Japanese music 1 compared to silence, and more when hearing white noise compared to Japanese music 2. We found a significant effect of the zone on this behaviour.

We did not find any significant effect of music on the behaviour « squawk ».

We did not find any significant effect of music on the behaviour « head upside down », but a significant effect of the interaction music*zone for zone 1 and zone 2.

(See table 5)

Table 5: LM analyses of time spent displaying spontaneous behaviours (in seconds) during the broadcast of stimuli or silence

Behaviour	Facotrs and interactions	p values (PermTest)	jap1 vs silence	jap2 vs white_noise	Musique *zone1	Musique *zone2
flapping_wings	*music*configuration*	**0.020**				
flapping_wings	*music*zone*	**0.023**				
climb_grid	*zone*	**0.016**				
climb_grid	*configuration*	**0.029**				
open_beak	*music*	**0.027**				
open_beak	*zone*	**<0,001**				
peck_grid						
peck_perch	*zone*	**<0,001**				
peck_perch	*music*configuration*	**0.033**				
preening	*zone*	**<0,001**				
shaking_feathers	*music*	**0.037**				
shaking_feathers	*zone*	**<0,001**	**<0,001**	**<0,001**		
squawk						
upside_down	*music*zone*	**0.006**			**<0,001**	**0.001**

Effect of music on the zone – all individuals included

We did not find any significant effect of classical music, modern music, Japanese music 1, Japanese music 2 nor silence on the zone.

We found a significant effect of white noise on the zone (0,01) : when hearing the white noise, the birds stay more in zone 3 than in zone 2 (p = 0,011) and more in zone 3 than in zone 1 (0,014).

(See figure 3.)

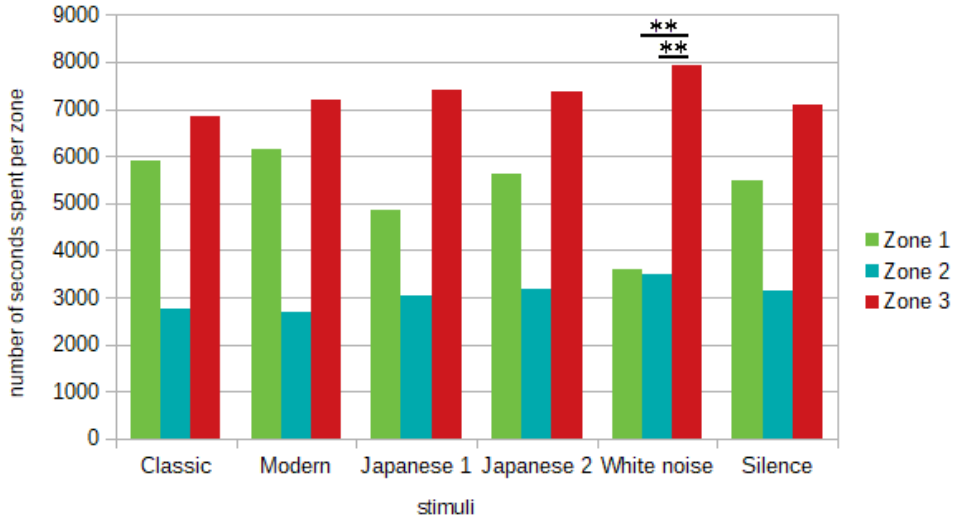

Figure 3. Number of seconds spent per zone depending on the type of music

Effect of music on the zone – per bird

No significant effect of music on the zone was found for the bird 27.

No significant effect of music on the zone was found for the bird fY.

No significant effect of music on the zone was found for the bird 28, but we found a significant effect of the interaction zone*moment in Japanese music 1 and a significant effect of moment in white noise.

No significant effect of music on the zone was found for the bird pp.

No significant effect of music on the zone was found for the bird RM.

A significant effect of music on the zone was found for the bird vf in white noise, yet we did not find any significant differences after pairwise comparisons and Bonferroni corrections.

No significant effect of music on the zone was found for the bird cc, yet we found a significant effect of the interaction zone*configuration in classical music, modern music, Japanese music 1, Japanese music 2, white noise and silence.

(See table 6).

Table 6: LM analyses of time (in seconds) spent on the different zones during the broadcast of stimuli or silence

Bird	Type of music	Factors and interactions	p values (PermTest)
27			
fY			
28	*Japanese 1*	*zone*moment*	**0.031**
28	*white_noise*	*moment*	**0.026**
pp			
RM			
vf	*white_noise*	*zone*	**0.025**
cc	*classic*	*zone*configuration*	**0.004**
cc	*modern*	*zone*configuration*	**0.008**
cc	*Japanese 1*	*zone*configuration*	**0.013**
cc	*Japanese 2*	*zone*configuration*	**0.018**
cc	*white_noise*	*zone*configuration*	**0.025**
cc	*silence*	*zone*configuration*	**0.012**

Discussion

The aim of this study was to explore the discriminating and reinforcing levels of music in seven jungle crows. We only found few significant effects of music on behaviour (for “open beak” and “shaking feathers”), and we did not find any significant effect of music or its absence on the time spent in a given zone, which does not allow us to conclude neither about the discriminating nor the reinforcing properties of music in jungle crows. Yet the birds spent more time in zone 3 (farther from the playing speaker) when the white noise was broadcasted, which suggests that they disliked it.

We found some significant effects of several interactions. Many of them are difficult to explain. Yet, the fact that we found a significant effect of the interaction zone*moment in Japanese music 1 for the bird 28, and a significant effect of the interaction zone*configuration in classical music, modern music, Japanese music 1, Japanese music 2, white noise and silence for the bird cc can be related to a perch preference: both spent most of their time on a specific perch, no matter which type of stimulus was broadcasted.

Discriminating level of music in jungle crows

Given that we only found few significant effects of music on behaviour, and we did not find any significant effect of music nor silence on the time spent in a given zone, we cannot conclude about the discriminating abilities of jungle crows regarding music. A lack of the cognitive abilities allowing discrimination seems very unlikely. Indeed, corvids are known for having quite high cognitive abilities (Emery, 2004); besides, colour discrimination **(**Bogale et al. 2012**)** and human faces categorisation (Bogale et al., 2011) have been evidenced in jungle crows. Furthermore, temporal resolution of complex sounds being more complex in birds than in humans (Dooling et al., 2002), this absence of behavioural differences depending on the music would not be due to poor auditory abilities. Thus, it is possible that the birds were not as interested in music as we could have expected.

Reinforcing effects of music in jungle crows

Given that we only found few significant effects of music on behaviour, and we did not find any significant effect of music nor silence on the time spent in a given zone, we cannot conclude about the reinforcing effects of music in jungle crows. In general, the birds did not display more positive nor less stereotypic behaviour when hearing music as compared to silence. A few studies evidenced that in some species, individuals do not display musical preferences and that music had few or no reinforcing effect, as is the case of pigeons (Watanabe et al., 2009) or rats (Otsuka et al., 2009), if not a negative effect, like in hens (Campo et al., 2005) and gorillas (Robbins and Margulis 2014). Yet those species are non-vocal learners, which is not the case of jungle crows. Nevertheless, even vocal learners do not always seem sensitive to music: in Watanabe et al.'s study (1998), two Java sparrows out of four did not show any musical preferences.

What about the vocal learning hypothesis?

Regarding Watanabe et al. hypothesis (2009), musical stimuli would be reinforcing in species that are capable of vocal learning. Jungle crows are vocal learners, yet neither reinforcing effect nor musical preferences could be evidenced in this study.

Nevertheless, over the past few years, less categorical assumptions have been hypothesised. First of all, vocal learning, instead of being a dichotomous feature, would range from non-vocal learners and limited vocal learners to complex vocal learners along a continuum (Arriaga and Jarvis, 2013). Besides, even non-vocal learners can display some features implying a certain sensitivity to music, although not as striking as the features evidenced in some vocal learners: for example, several rhythmic competences like beat discrimination or production have been evidenced in chimpanzees (Pan troglodytes) (Arcadi et al., 1998; Dufour et al., 2015) and gorillas (Gorilla gorilla gorilla, and Gorilla beringei beringei) (Schaller, 1963), pigeons (Hangmann and Cook, 2010) and collared doves (Streptopelia decaocto) (Ballintijn and ten Cates, 1999); besides, music has a reinforcing effect in zoo-housed western lowland gorillas (Western lowland gorillas) (Wells et al. 2006) and captive dogs (Canis lupus familiaris) (Wells et al., 2002; Boone and Quelc,h 2003; Kogan et al., 2012). Degus even prefer Chilean folk music to Western music and silence (yet it is important to note that auditory communication is highly developed in this species). Although jungle crows are capable of vocal learning, we do not know how strong is this ability; it is thereby difficult to conclude about a prospective relationship between vocal learning and musical sensitivity in those birds. Furthermore, as we describe it below, several limitations could have affected the results.

The case of white noise

The only stimulus that has an effect on the time spent in a given zone is the white noise: the birds spent more time in zone 3 than in zone 1 and 2 when hearing white noise, i. e. they stayed away from the speaker broadcasting white noise, suggesting that they disliked it. In this experiment, white noise was used as a sound control, because we thought that it was a neutral stimulus which could have allowed us, in case some birds would have displayed musical preferences, to check that they would have been reinforced by the music and not by any type of noise. Yet those results show us that this stimulus was rather aversive; the use of white noise as a neutral stimulus should therefore be considered carefully in future studies: as it happens, several researches used white noise as an aversive stimulus.

Limitations

Because of several limitations, we cannot draw out clear conclusions from the results.

First of all, the fact that the crows were captive wild animals probably impacted their behaviour: it is important to note that they were not familiar with the main experimenter, and they had to be caught from their usual indoor cage so as to be moved in the outdoor aviary for the test. Being caught was probably an important stress for them, given the way they struggled. Besides, they were isolated, which was probably another factor of stress since crows usually live in large and complex societies (Emery, 2004). Indeed, once in the experimental aviary, the birds would spend most of their time jumping from one perch to another as if stressed. Moreover, the change in their environment might have influenced the way they reacted to the music: more specifically, we could not control the sound environment of the birds since, the aviary being outside, they could hear all types of noises (engines and car horns, squawking crows,…); furthermore the laboratory was located very close to a sports field, so we could regularly hear people shout while playing. Second, the video coding was sometimes uneasy due to the bars of the aviary, which could hinder a good vision (all the more because the birds did not always stand on the perches), and the winter season, causing an early nightfall and some difficulties to clearly distinguish the bird's behaviour when the environment darkened.

Conclusion

The jungle crows did not display discriminating nor reinforcing properties of music in our study. A part from the possibility that this species would not be sensitive to music at all, it is likely that our very small sample and the experimental conditions would have altered the birds' behaviour. Therefore, we cannot draw any conclusion from this study. Further researches should be conducted in corvids, which sensitivity to music has never been studied before, as well as in other birds.

Declarations of interest: none.

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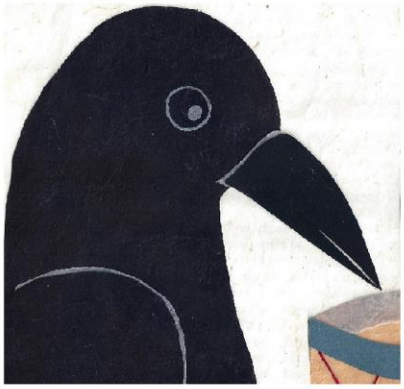
Chapitre 3 : Production sonore et rythmique chez les calopsittes élégantes et les corbeaux à gros becs



3.1. Production sonore chez les calopsittes élégantes

Combinatory sound object play in cockatiels: a forerunner of music?

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Abstract

An interest in producing sounds during play behaviour might be a forerunner for music. Thus, we explored object play behaviour involving sounds in cockatiels (*Nymphicus hollandicus*). We provided them with several objects producing sounds and recorded sound production, spontaneous warbles and drumming during breeding, pre- and post-breeding. Birds manipulated the objects in a playful way. They manipulated them less during breeding than during pre- and post-breeding, but the proportion of manipulations producing sounds were higher during post-breeding and breeding than during pre-breeding. Males manipulated the objects more frequently and produced more sounds than females. Youngsters manipulated the objects more than adults. One bird repeatedly put a bell on a xylophone; we discuss several possible explanations for the behaviour, including tool use. Only males warbled and drummed, and during breeding only. Our results suggest an enriching effect of the objects on the birds. Many aspects of musicality remain to be studied.

Key words: music, play, birds, warble, drumming, tool-use, psittaciformes, social learning.

Introduction

Sound producing play as a forerunner of music

Pellegrini et al. (2007) explain that a playful behaviour involves participants more concerned with the behaviour itself than with its function. Play behaviour enables to develop innovative behaviour by allowing juveniles to sample their environment (Pellegrini et al., 2007).

We suggest that an interest in producing sounds during play behaviour might be a forerunner for evolving sound-related cultural phenomena like music. Indeed, when exploring the origins of music in humans, Cross & Morley (2008) suggest that both music and play share several features. Based on a more ontogenetic perspective, Papousek (1996) describes early musical behaviour as forms of play in infants.

Both music and play are difficult to define and yet seem to share several characteristics. O'Hara et al. (2017), who review play behaviour in parrots and corvids, describe five criteria of play broadly accepted: (1) intrinsically rewarded, (2) seems to serve no purpose, (3) repeatedly performed, (4) voluntarily and (5) under relaxed conditions. The criteria (1), (2), (3) and (4), at least, can be easily applied to music too.

Object play consists of interacting with objects or combining them with others (O'Hara et al., 2017) e.g. through combinatory actions, which bring several objects into direct contact with each other (Auersperg et al., 2015); this type of complex manipulatory behaviour appears in 8-month-old children (Rat-Fischer et al., 2012) and can be related to instrumental playing. Musicality and play also allow the development of cognitive flexibility (for music see Cross & Morley, 2008; for play Auersperg et al., 2014; Auersperg et al., 2015): according to Stevens (2014), combinatory play is a creative process involving fluid interconnectedness between hemispheres and brain regions; as for music, it improves interactions between the two hemispheres in musicians who began to practice before being seven (Münte et al., 2002).

The vocal learning hypothesis

When it comes to music, non-human primates, in spite of some studies showing tempi and musical preferences (McDermott & Hauser, 2007; Sugimoto et al., 2010; Mingle et al., 2014) do not seem as interested in music as we could have expected, since they are phylogenetically very close to us. However, birds display in their songs rules similar to those inducing emotions in humans who listen to music (Rothenberg et al., 2014) and some birds, especially parrots, show numerous musical abilities such as singing in response to a musical stimulus (Bottoni et al., 2003) or entrainment to a rhythm (Patel et al., 2009). Watanabe (2009) suggests that musical stimuli are only reinforcing in vocal learner species, such as songbirds and parrots. Vocal learning can also be related to object play, since in one African grey parrot, Pepperberg et Shive (2001) showed that communicative and physical objects combination abilities developed in a parallel way.

Object play behaviour and tool use in birds

Play enables animals to learn and practice relevant behaviour increasing survival, in spite of not being immediately intrinsically rewarded (O'Hara et al., 2017). Combinatory actions have been studied in corvids like New Caledonian crows (*Corvus moneduloides*), which combine objects they find as soon as they leave the nest (Rat-Fischer, 2017) and psittaciforms (Auersperg et al., 2015). Complex object exploration even exists in non-tool using species (Gadjon et al., 2014) like common ravens (*Corvus corax*) (Rat-Fischer, 2017). Besides, in several parrot species, object play behaviour seems to be maintained into adulthood (Auersperg et al., 2014; Auersperg et al., 2015). In human babies, complex manipulatory behaviour is thought to be a possible forerunner of tool use (Rat-Fischer, 2017). Tool use has also already been observed in several parrot species. Figaro, a male Goffin cockatoo (*Cacatua goffiniana*), made and used a stick in order to reach food otherwise unattainable (Auersperg et al., 2012). Keas (*Nestor notabilis*) (Auersperg et al., 2011; Gadjon et al., 2011) and hyacinth macaws (*Anodorhynchus hyacinthinus*) (Borsari & Ottoni, 2004) have also shown such abilities. More surprisingly, other parrots, palm cockatoos (*Probosciger aterrimus*), can create tools with which they drum on hollow trees (Wood, 1984) with individual styles, performing regular beat productions and repeated

components in a consistent context, sharing thus key rudiments of human instrumental music (Heinsohn et al., 2017).

The current study

The aim of this study was to explore object play behaviour involving sounds in cockatiels (*Nymphicus hollandicus*), by providing them with several objects with which they could produce sounds. We also recorded spontaneous warbles and drummings. Cockatiels are cacatuidaes, like palm cockatoos. They also belong to the psittaciforme order, in which birds show play behaviour, are capable of vocal learning and are known to have high abilities and to share complex cognitive skills with primates.

We made the following hypotheses:

(1) The cockatiels should play with the objects and produce more sound-producing manipulations than non-sound-producing ones, because as vocal learners they should have a certain sensitivity to sounds.

(2) Males should be more motivated to produce sounds than females, especially during courtship behaviours and the breeding period. Indeed, in several bird species, songs and rhythms are mainly performed by males and seem to be related to courtship (e.g. Dalziell et al., 2013; Ota et al., 2015; Soma et al., 2015). In palm cockatoos, drumming is mostly performed by males (Heinsohn et al., 2017).

(3) Juvenile birds should manipulate and interact more with the objects. Indeed, play is more frequent in juveniles (Pellegrini et al., 2007). Besides, juvenile birds show a more important exploratory behaviour in many species (Greenberg & Mettke-Hoffman, 2001).

Materials and methods

Ethic statement

The birds were housed according to standard conditions approved by the French National authorities. This study is in line with French and European legislation for animal care and was approved by the Ethical Committee for Animal Experimentation Charles Darwin (authorization number #7035 2016093011025283 v2).

Subjects and housing conditions

This study was held in the Laboratoire Ethologie Cognition Développement (LECD) in Nanterre University (France), with thirteen cockatiels (*Nymphicus hollandicus*) (see Table 1). The birds were housed in an indoor aviary with no window. The temperature was 23°C and the light was turned on from 9 am to 11 pm. Three stainless steel work benches (155*55*84 cm) were located next to the left wall and there were two big perches in the middle of the room. Toys, cardboards and two triangle suspended perches were also available. Birds were fed ad libitum with seed Deli Nature for large parakeets, various fruits and vegetables, aniseed sand and water.

Table 1. Name, age, sex and birthdate of the birds

Bird	Age when involved in the experiment	Gender	Birthdate
Hermès	3 years 5 months	Male	29/05/13
Callisto	3 years 3 months	Female	13/07/13
Viviane	3 years 3 months	Female	12/07/13
Nephtys	3 years 2 months	Female	31/08/13
Seth	3 years 2 months	Male	31/08/13
Bahloo	3 years 2 months	Male	31/08/13
Skadi	2 years 4 months	Female	12/06/14
Odin	2 years 4 months	Male	06/06/14
Loki	2 years 4 months	Male	15/06/2014

Isis	2 months 13 days	Female	26/11/2016
Éole	1 month 21 days	Male	18/12/2016
Gaïa	1 month 19 days	Female	20/12/2016
Morgane	1 month 16 days	Female	23/12/2016

Experiments

Several objects with which the birds could produce sounds were disposed on a bench: a xylophone, several bells and handmade maracas (bottle tops filled with rice and wearing bells).

Cockatiels being highly neophobic, we first put the objects in the aviary with food around so that they could get used to them during 11 habituation sessions (138 minutes in total).

Experiment 1

Then 35 one hour watching sessions allowed us to see in which way and context the animals would spontaneously use the objects. We divided the experiment in three periods: the pre-breeding period (11 sessions), the breeding period (15 sessions) and the post-breeding period (9 sessions).

The breeding period was stimulated by increasing photoperiod, installing nest boxes and moistening the aviary. It ended when the chicks were independent enough for us to take out the nest boxes. The chicks born during the breeding period were only involved in the experiment during the post-breeding period, thus this period counted four more birds than the previous ones. Three types of sound-producing behaviours were recorded:

- ✓ behaviours involving sound-producing objects: putting the bell on the xylophone, walking on the xylophone, lifting its keys, tapping them, shaking maracas and little bells, manipulating little bells, pulling little bells
- ✓ behaviours without physical objects: warbles
- ✓ non sound-producing behaviours involving the instruments were also recorded: putting a seed on the xylophone, eating cardboard, manipulating silently the instruments

- ✓ behaviours using a support: drumming, which consisted in hitting briskly and repeatedly a support with the beak

Experiment 2

Six months later, another 10 sessions were conducted, in order to determine whether the birds would prefer to manipulate sound-producing over silent objects. The same instruments were available for the birds, but each kind of instrument (except for the xylophone) was given in two exemplars, a sound-producing one (for example, a regular bell) and a silent one (for example, an empty bell). All the sessions took place one to three times a day from Monday to Saturday, in the morning and/or the afternoon.

The same behaviours as described previously were recorded

(a) (b) (c) (d) (e)

Figure 1. Pictures of the objects: (a) bells, (b) cardboard roll, (c, d) handmade maracas and (e) xylophone

Statistical analysis

All the analyses were ran using the software R v3.4.3 (R Core Team, 2017). Generalized linear mixed model analyses (GLMM) were conducted using the add-on package lme4 (Bates et al., 2015).

For experiment 1, we conducted GLMM analyses in order to test whether the birds show more or less manipulation of the objects and sound-producing behaviours depending on age, sex and periods. As the youngest birds were born during the breeding period, we first performed the analyses with the adults only to compare their behaviours according to sex and periods (breeding, pre- and post- breeding). Only nine videos were analysed for each period (randomly chosen), in order the observation time to be the same for each period. The

dependent variables were (1) total amount of time (in seconds) spent manipulating the objects, (2) amount of time (in seconds) spent producing sound with the objects, (3) the ratio of the time spent producing sound with the objects on total time spent manipulating the objects, (4) time (in seconds) spent producing warbles, (5) time (in seconds) spent drumming on a support using the beak. We analysed each of these variables in a distinct model. Sex and period were included as fixed effects in these models. Then, we conducted distinct analyses including all the individuals but only the post-breeding sessions, in order to compare behaviour of the young and adult birds during this period. For these analyses, the dependent variables were (1) total amount of time (in seconds) spent manipulating the objects, (2) amount of time (in seconds) spent producing sound with the objects and (3) the ratio of the time spent producing sound with the objects on total time spent manipulating the objects. Sex, age, and age x sex interaction were included as fixed effects. In all models, the identity of the bird and the watching session were also included as a random effect to control for pseudo-replication. We used a gamma distribution when the dependent variable was expressed as a duration, and a binomial distribution for the ratio of time spent producing sounds with the objects on total time spent manipulating the objects. We used the "Anova" R function to obtain p-values for each effect (by comparing the likelihood of the model without the tested effect and those of the full model). In addition, we used post-hoc Tukey tests (Tukey, 1949) to perform pairwise comparisons among the three periods where a significant effect of periods was found. Student tests were also conducted in order to see whether the birds manipulate more often in group or alone. Finally, as described further in the result section, one of the birds showed an unexpected behaviour (putting or dropping a bell on the xylophone). We conducted a GLM analysis with gamma distribution to compare the amount of time spent by this bird doing it according to the periods (breeding, pre-breeding, post-breeding).

For experiment 2, we conducted other GLMM analyses in order to test whether the birds spent more or less time manipulating the sound-producing objects as compared to the silent objects. The dependent variable for these analyses was the total time spent manipulating the objects (in seconds). Fixed effects were the type of object (sound-producing or not), age, sex, and interactions between (1) type of object and sex, and (2) type of object and age.

Again, we included the identity of birds and the watching session as random effects. We followed the same procedure as above to test for the significance of each effect.

Results

All mean durations are calculated by bird and by one hour session.

Experiment 1

Manipulation and sound-producing behaviour in adults

As shown in table 2, the birds spent more time manipulating the objects during the post-breeding period than during the pre-breeding period and more during the pre-breeding period than during the breeding period. We found a similar pattern when focusing only on sound producing manipulation (Figure 2). However, manipulation was more sound-producing during the breeding period than during the pre- and post-breeding period, and during the post-breeding period than during the pre-breeding period *(*i.e. higher ratio between sound-producing manipulation and total manipulation) (Figure 3). Males manipulated the objects more, and spent more time doing sound-producing manipulation as compared to females (Figure 4). The ratio of sound-producing manipulation on total manipulation did not differ according to sex.

In addition, the birds warbled and drummed only during the breeding period, and only males warbled and drummed. However, the effect of period is significant but not the effect of sex.

Table 2. Results of GLMM analyses conducted for experience 1 (adults only, all three

Dependant variable			χ^2	df	p			
Distribution	Effects	Means			LRT test	Pre-breeding vs breeding	Breeding vs post-breeding	Pre-breeding vs post-breeding
Time spent manipulating the objects								
gamma	Period	Pre-breeding: 73.06 s breeding: 44.67 s post-breeding: 97.61 s	5.22	2	0.002	<0.001	<0.001	<0.001
	Sex	Females: 30.63 s Males: 104.7 s	7.43	1	0.06	–	–	–
	Bird identity	–	5711.4	1	<0.001	–	–	–
	Watching session	–	6615.7	1	<0.001	–	–	–
Time spent producing sound with the objects								
gamma	Period	Pre-breeding: 72 s breeding: 42.89 s post-breeding: 89.33 s	4.04	2	0.04	<0.001	<0.001	<0.001
	Sex	Males: 98.03 s Females: 30.63 s	7.24	1	0.007	–	–	–
	Bird identity	–	5721	1	<0.001	–	–	–
	Watching session	–	6625	1	<0.001	–	–	–

Dependant variable			χ^2	df	p			
Distribution	Effects	Means			LRT test	Pre-breeding vs breeding	Breeding vs post-breeding	Pre-breeding vs post-breeding
Sound-producing manipulation/total manipulation								
binomial	Period	Pre-breeding: 0.81 breeding: 0.91 post-breeding: 0.88	8	2	<0.001	<0.001	0.03	<0.001
	Sex	Males: 0.27 Females: 0.04	7.1	1	0.008	–	–	–
	Bird identity	–	28.2	1	<0.001	–	–	–
	Watching session	–	513.9	1	<0.001	–	–	–
Warbling (yes or not)								
binomial	Period	–	0.72	1	ns	–	–	–
	Sex	–	3.11	1	ns	–	–	–
	Bird identity	–	12.34	1	ns	–	–	–
	Watching session	–	14.22	1	ns	–	–	–
Drumming (yes or not)								
binomial	Period	–	1.99	1	ns	–	–	–
	Sex	–	1.55	1	ns	–	–	–
	Bird identity	–	8.75	1	ns	–	–	–
	Watching session	–	9.98	1	ns	–	–	–

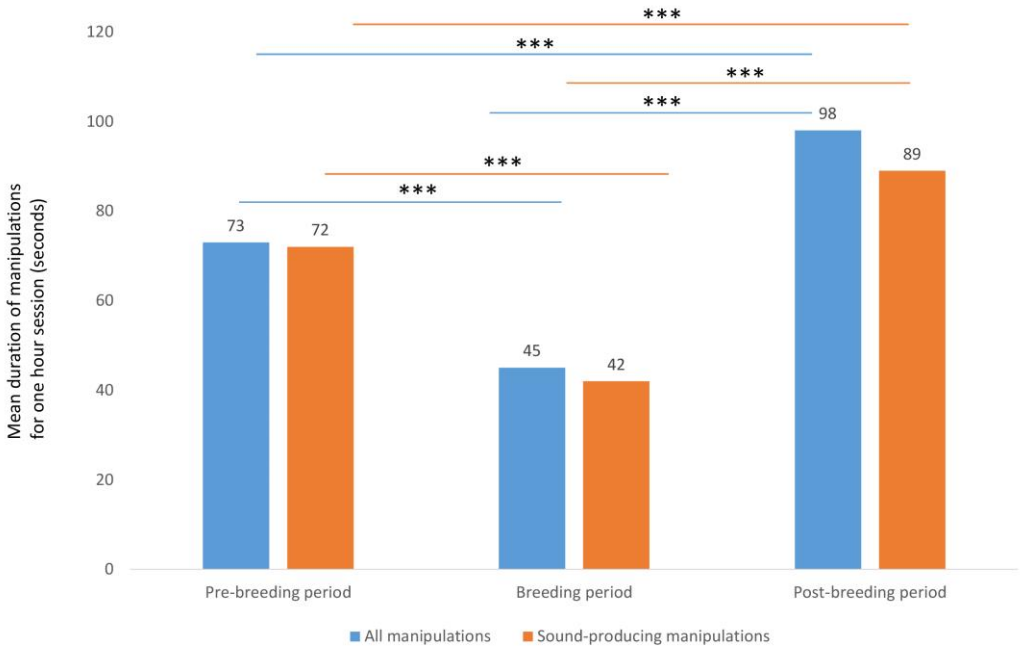

Figure 2. Mean duration of all manipulations and sound-producing manipultations depending on period (adults)

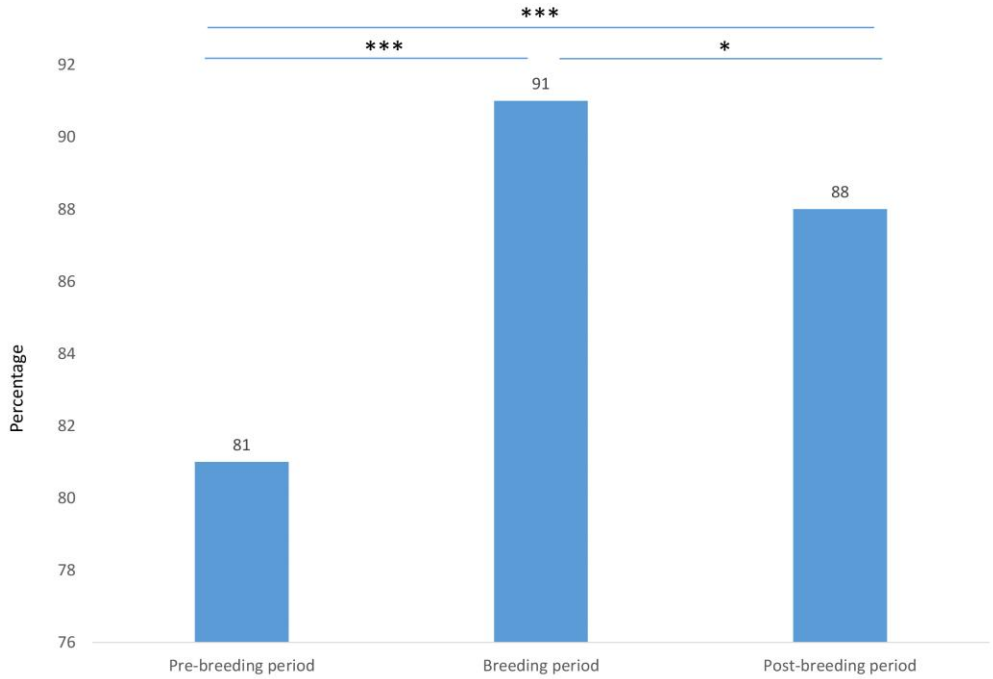

Figure 3. Percentage of sound-producing manipulations depending on period

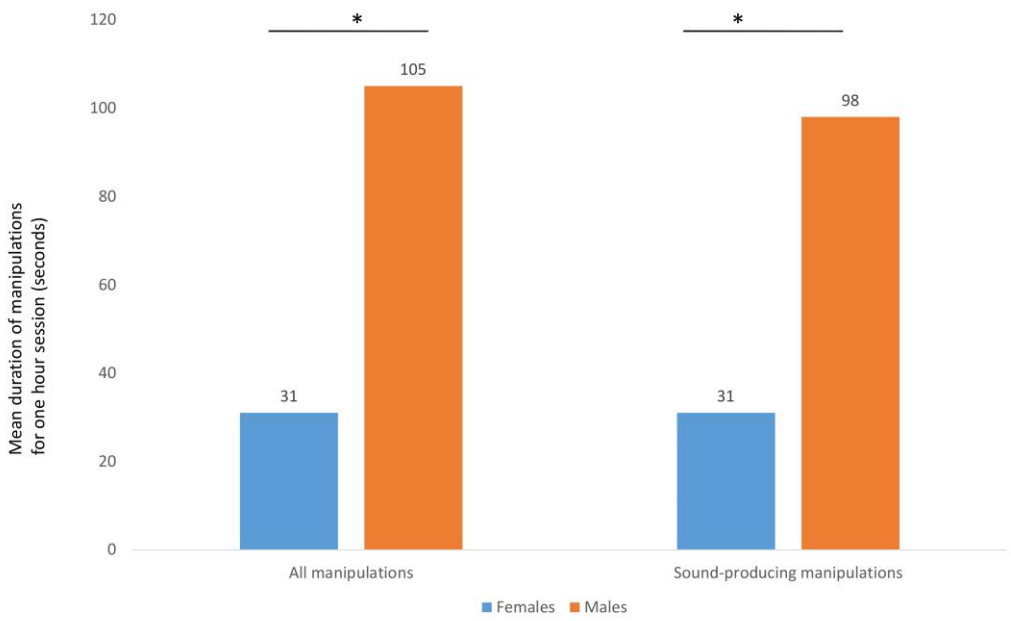

Figure 4. Mean duration of all amnipulations and sound-producing manipulations depending on sex

<u>Manipulation and sound-producing behaviours in young birds versus adults</u>

As shown in table 3, young birds spent more time manipulating the objects and producing sound with the objects than adults during the post-breeding period (Figure 5). The ratio of sound-producing manipulation on total manipulation did not differ between young and adult birds. Again, males spent more time manipulating the objects and producing sound with them than females. The ratio of sound producing manipulation over total manipulation is also significantly higher in males than in females. This appears to be true for both young and adults. Indeed, the age x sex interaction effect is not significant.

Table 3. Results of GLMM analyses conducted for experience 1 (Post-breeding period only, all individuals

Dependant variable			χ^2	df	*P* (LRT test)
Distribution	Effects	Means			
Time spent manipulating the objects					
gamma	age	young: 364.5 adults: 103.06	9.04	1	0.01
	Sex	Males: 208.58 Females: 162	7.66	1	0.02
	Sex:age	–	1.48	1	ns
	Bird identity	–	2630.6	1	<0.001
	Watching session	–	4447.3	1	<0.001
Time spent producing sound with the objects					
gamma	age	young: 337.12; adults: 94.77	8.98	1	0.01
	Sex	Males: 188.83 Females: 152.64	7.45	1	0.02
	Sex:age	–	1.4	1	ns
	Bird identity	–	2500.1	1	<0.001
	Watching session	–	3748.4	1	<0.001
Sound-producing manipulation/ total manipulation					
binomial	age	young: 0.51 adults: 0.18	5.71	1	ns
	Sex	Males: 0.35 Females: 0.23	7.08	1	0.03
	Sex:age	–	3.91	1	ns
	Bird identity	–	113	1	<0.001
	Watching session	–	302.2	1	<0.001

)

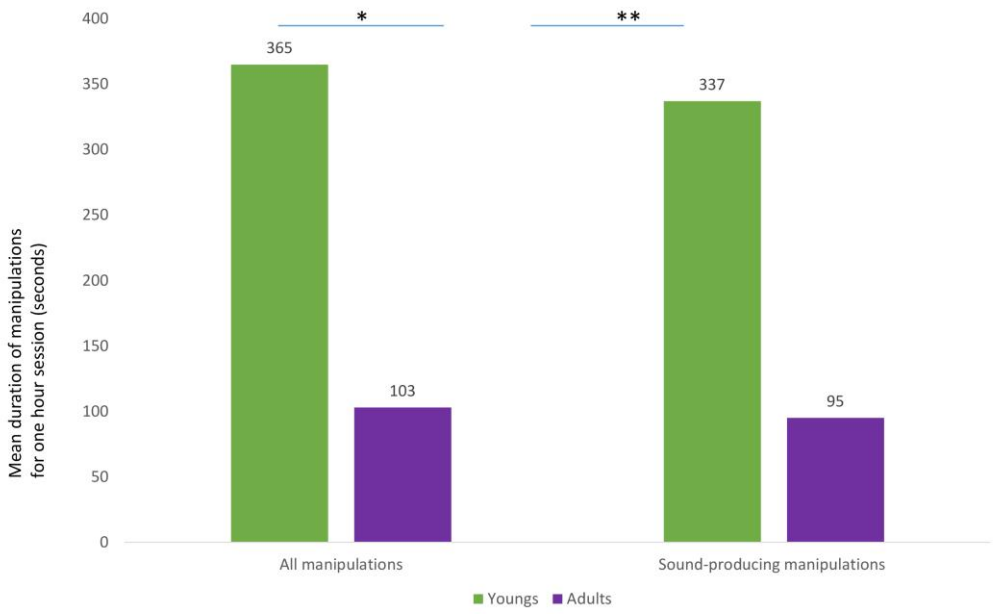

Figure 5. Mean duration of all manipulations and sound-producing manipulations depending on age (post-breeding period)

<u>Manipulation in group versus alone</u>

Adults spent more time manipulating the objects alone (mean time = 78.5 seconds) than in group (mean time = 3.82 seconds) (t = 2.69, df = 89.96, p = 0.008). They also did more sound-producing manipulation alone (mean time = 75.21 seconds) than in group (mean time = 3.44 seconds) (t = 2.62, df = 89.95, p = 0.01) (Figure 5). Similarly, the young birds spent more time manipulating the objects alone (mean time = 82.07 seconds) than in group (mean time = 10.6 seconds) (t = 2.75, df = 41.49, p = 0.008), and they did more sound-producing manipulation alone (mean time = 63.77 s) than in group (mean time = 9.32 s) (t = 2.38, df = 41.78, p = 0.02). (see Figure 6).

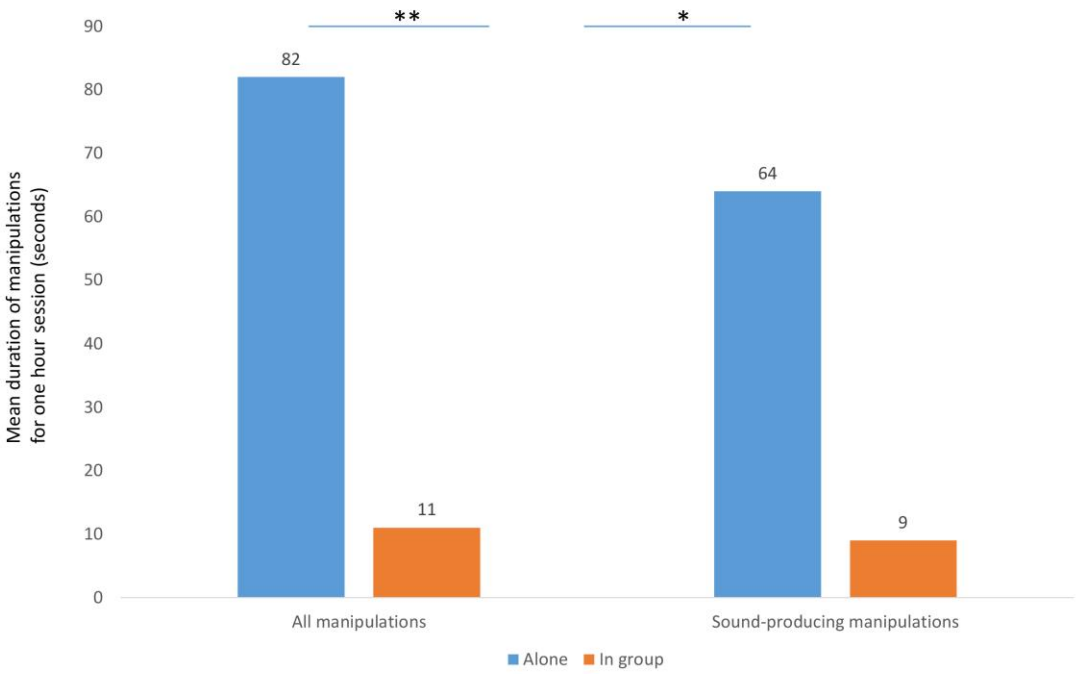

Figure 6. Mean duration of all manipulations and sound-producing manipulations depending on group

Unexpected behaviour

One of the birds, Seth, showed an unexpected behaviour: he put or dropped a bell on the xylophone 198 times. This was performed deliberately as Seth picked up a bell at some distance (3 to 15 cm) from the xylophone, approached it with the bell still in his beak, then put (159 times) or dropped (39 times) the bell on the xylophone. He also picked up two seeds, one from his bird feeder (about 50 cm from the xylophone) and the other from the work bench (about 10 cm from the xylophone) and put them respectively 3 and 2 times on the xylophone (this event happened in two different days, within three days).

There is a significant effect of period on this behaviour (GLM, X^2 (2) =16.16, p <0.001). In particular, post-hoc Tukey tests show that this behaviour appeared significantly more during the pre-breeding period than during the post-breeding period (respectively 614 and 132 seconds, p <0.001), and more during the pre-breeding than during the breeding period (respectively 614 and 51.5 seconds, p = 0.003). There is no significant difference for this behaviour between the breeding and the post-breeding periods (p = 0.95) (Figure 7).

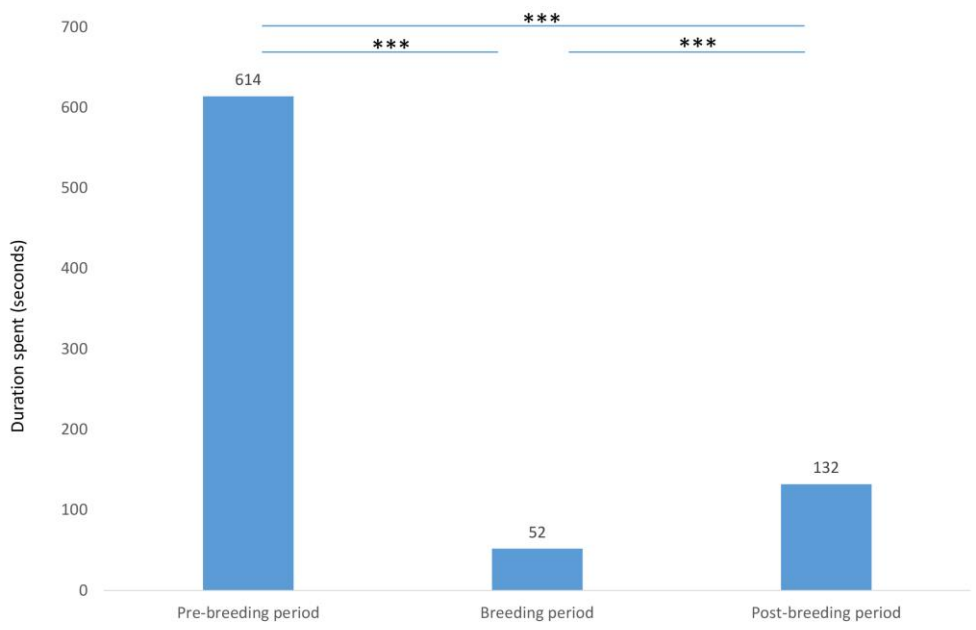

Figure 7. Duration spent by Seth putting the bell on the xylophone depending on period

Four birds also put a bell on the xylophone after Seth started it: Bahloo (Seth's brother) did it three times, the first one starting on the morrow after Seth started (yet Seth had already done it 15 times by then); Odin did it twice, the first one being two months after Seth started, Loki three times, the first one being four months after Seth started, and Isis (Seth's daughter) once, four months after her birth (i.e. five months after Seth started to do it).

Experiment 2

As shown in table 4, the birds manipulated more the silent objects than the sound-producing objects. However, there is a significant effect of the type of objects x sex interaction. As shown in Figure 8, females manipulated the silent objects more than the sound-producing objects, whereas males manipulated the sound-producing objects more than the silent objects. Finally, young birds manipulated the objects more than adults in general.

Table 4. Results of GLMM analyses conducted for experience 2

Dependant variable			χ^2	df	*P* (LRT test)
Distribution	Effects	Means			
Time spent manipulating the objects					
gamma	Type of object	sound-producing: 0.99 silent: 1.34	7.84	1	0.005
	Age	young: 41.63 adults: 0.28	4.7	1	0.03
	Sex	Males: 0.56 Females: 1.67	0.83	1	ns
	Type of object: Sex	–	36.24	1	<0.001
	Type of object: age	–	3.08	1	ns
	bird identity	–	458.84	1	<0.001
	watching session	–	1170.2	1	<0.001

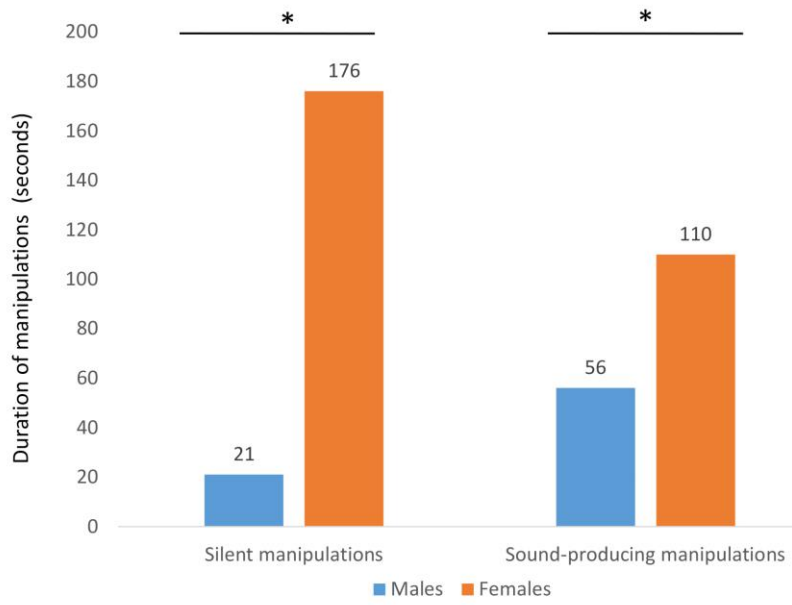

Figure 8. Duration of silent manipulations and sound-producing manipulations depending on sex

Discussion

Can the cockatiels' behaviour be qualified as playful?

During this experiment, our cockatiels displayed a behaviour that matches with the five play criteria suggested by O'Hara et al. (2017): (1) intrinsically rewarded, (2) seems to serve no purpose, (3) repeatedly performed, (4) voluntarily and (5) under relaxed conditions. As expected, they also produced significantly more sound-producing manipulations than non-sound-producing manipulations. Besides, Seth's use of the bell (putting it or dropping it on the xylophone in order to produce a sound) also implies combinatory actions, i.e. actions that bring several objects into direct contact with each other (Auersperg et al., 2015). Thereby, our study indicates that cockatiels can show sound-producing play behaviour, sometimes involving combinatory actions.

Considering the repetitive nature of the animals' interaction with the objects, their presence is likely to have an enriching effect on the birds' environment. This suggests that providing various objects to the birds, including sound-producing ones, can be a factor of animal welfare.

Experiment 1

<u>Manipulation and sound-producing behaviour in adults</u>

Based on the first experiment, we showed that the birds manipulate more in general and have more sound-producing manipulations during the post-breeding period as compared to the pre-breeding period, and also during the pre-breeding period as compared to the breeding period. The decrease of objects manipulation during the breeding period could be related to the emergence of very time-consuming new behaviours, particularly taking care of eggs and chicks, which were performed by both sexes. The high post-breeding manipulation could be related to the amount of exposure to the objects: the birds were more familiarized with them after the breeding period and could have developed certain interaction patterns producing sounds, pursuing those behaviours afterwards. However, there was a higher ratio between sound-producing manipulation and total manipulation during the breeding period,

which could show a higher motivation to make sounds with the objects during the breeding period. The object manipulation could also be louder during the breeding period because of an increase of stress hormone, inducing a more vigorous manipulation; indeed in some bird species, the concentration of corticosterone varies during the breeding period (Casagrande et al., 2018). Our results also show that males manipulate more in general and have more sound-producing manipulations than females. Therefore, whether those sound-manipulations can be used as a display behaviour and are influenced by the breeding period or not still needs to be studied.

On the contrary, warbles and drummings appear only during the breeding period, which indicates that those behaviours can be considered display behaviours. Indeed in many bird species, songs and rhythms have been mostly observed during the mating season (Searcy & Anderson, 1986) like in canaries, which tend to produce more sexy phrases (a particular phrase preferred by females, Vallet et al., 1995) during the reproductive period (Leitner et al., 2001) and palm cockatoos, whose drumming is supposed to be a display behaviour (Heinsohn et al., 2017).

Regarding warbles and drummings, we found no significant differences between males and females, despite the fact that only males warbled and drummed. This could be due to our small sample and to the fact that, among the six tested males, only three showed those behaviours (Odin sang and drummed, Seth sang only and Hermès drummed only). The three males involved in those behaviours were the only ones involved in a long-term pair relationship, which could explain why they displayed them. Although it has been thought that songs are mainly performed by males in songbirds (see for example Searcy & Anderson, 1986), in many species, there is increasing evidence of female songs (Langmore, 1998). Data on warbles in parrot species are scarcer and in many of them both sexes warble (Bradbury et al., 2016); cockatiels would be special among parrots in this respect.

Manipulation and sound-producing behaviours in young birds versus adults

In line with our hypothesis, young birds manipulated the objects more than adults, in general and with sound-production manipulations. According to Greenberg & Mettke-Hoffman (2001), young birds exploration could be enhanced by the fact that they move in an entirely novel environment and remain under their parents' protection; thus this exploration

could allow them to acquire information (profitable resources for example) without taking too much risk. Neophilia could also have been selected because it can help juveniles to become more independent (for example when foraging for food). This neophilia would decrease when the novel environment becomes familiar. Pellegrini et al. (2007) also highlight the fact that play behaviour appears in juveniles more frequently than in adults.

Manipulation in group versus alone

In general, the birds manipulate more often alone than together. Producing sounds and manipulating the objects would thus be mainly an individual behaviour. Yet, since the cockatiels produce more sounds during the breeding period, this individual behaviour could be a display directed toward a non-participating audience.

Unexpected behaviour – a first case of tool use in cockatiels?

Although not expected, one of the most interesting actions observed during this study is Seth's behaviour, as he repeatably combined the bell with the xylophone while producing sound. The high frequency of this behaviour (198 times) and the way it was conducted clearly shows that he did it on purpose. The bird also tried to put a seed on the xylophone five times but he did not persevere in this behaviour, probably because this action produced no sound, suggesting that this behaviour was reinforced by the sound it produced.

Although Seth was almost the only bird to conduct this behaviour, this performance could be a sexual display and be related to the behaviour observed by Heinsohn et al. (2017) in palm cockatoos, since both cockatiels and palm cockatoos are cacatuidaes. Indeed, Seth performed this behaviour mostly during the pre-breeding period. The fact that it decreased during breeding might be because he was too busy taking care of the eggs and chicks to continue it. Seth could also have gotten bored of the behaviour, explaining why, although this conduct increased a little after the breeding period, it did not reach its previous level.

Alternatively, Seth’s behaviour can also be described in terms of combinatory actions, i.e. actions which bring several objects into direct contact with each other (Auersperg et al., 2015). Object combination has already been observed in new Caledonian crows (Kenward et al., 2011) and in psittaciforms (Auersperg et al., 2015). Thereby, this behaviour could be a case of combinatory object play that is repeated within a circular reaction.

If we assume that Seth's behaviour is not simply a playful circular reaction (as explained above) but actually a social display directed at conspecifics, it could indeed qualify as tool use according to some popular definitions (e.g. van Lawick-Goodall et van Lawick, 1970) but not to others (St Amant & Horton, 2008; Mangalam & Fragazsy, 2018). In non-human animals, tool-use has mostly been observed in a feeding context, like in chimpanzees (*Pan troglodytes*), which fish termites by inserting a twig in termites' mounds (Suzuki et al., 1995), New Caledonian crows, which extract insect larvae from tree holes with twigs (Hunt, 1996), or Goffin cockatoos like Figaro, a male who made and used a stick in order to reach food otherwise unattainable (Auersperg et al., 2012). Other interesting uses of tools have been recorded, like crows using a tool in order to interact with a new object (Wimpenny et al., 2011), or a female chimpanzee, who selected a stem of grass to remove debris from the teeth of a dead body (van Leeuwen et al., 2017). But tools can also be used in order to modify a sound, as is the case of tree crickets (*Oecanthus burmeisteri*), which increase the intensity of their calling song using a leaf as a sound baffle (Prozesky-Schulze, 1975) or wild orang-utans (*Pongo pygmaeus wurmbii*), which exaggerate their perceived size to the listener, lowering the frequency of their calls thanks to stripped leaves inserted in their mouth (Hardus et al., 2009). Palm cockatoos (Heinsohn et al., 2017) are also known for creating tools in order to produce sounds. To our knowledge, no tool-use has been observed in cockatiels yet; the fact that the bell is not used to get food but, as in palm cockatoos, to produce sounds is also noteworthy.

Experiment 2

During the second experiment, the females manipulated the silent objects more than the sound-producing ones, whereas it was the opposite for the males. Thus, males seem to be more motivated to produce sounds. As suggested before, those sound-producing manipulations could be displays directed toward females.

It is important to note, though, that this experiment was conducted eight months after moving the birds to a new aviary, in which the acoustic characteristics could be different from the previous one, and thus took place after a change in their environment. Since we observed other behavioural changes (such as more screaming), it is likely that this would

have affected the results, inducing less objects manipulations during this period. Therefore we must be cautious about the results of the second experiment.

Combinatory actions producing sounds: could this be more than just play?

As described above, the behaviour observed in our birds can be described in terms of play and combinatory actions (e.g. O'Hara et al., 2017; Auerperg et al., 2014; Auersperg et al., 2015). Yet, some aspects of this behaviour may also be related to a certain form of musicality. First of all, the choice of birds to manipulate more with than without sounds remains to be questioned. Besides, the high ratio of sound producing manipulations during the breeding period suggests a sexual display. In "The descent of man" (1871), Darwin suggests that music could have evolved in relationship with sexual selection, an hypothesis that other authors agree with, since music could have evolved because it confers a sexual advantage (Miller, 2000; Cross & Morley, 2008). Indeed in several bird species, many songs and rhythms seem to be related to courtship; for instance males superb lyre-birds (*Menura novaehollandiae*) perform songs and dance during display (Dalziell et al., 2013), blue capped cordon bleus (*Uraeginthus cyanocephalus*) perform tap dancing in a complex courtship display (Ota et al., 2015), or males Java sparrows (*Lonchura oryzivora*) coordinate their bill-click sounds with the syntax of their song-note sequences (Soma et al., 2015). Another hypothesis suggested by Cross & Morley (2008) is that in altricial species (as is the case of mankind, but also cockatiels) several factors, such as the accommodation to a population with increasing members with access to juveniles modes of cognition, motivation and behaviour, would have enhanced in adults musicality as a mean of assimilating juveniles exploratory modes.

Stevens (2014) describes combinatory play as a vital component of the creative process in art. All those observations pave the way for more studies about the origins of musicality in relationship with the emergence of exploration and combinatory play behaviour. They also suggest that musicality may not be unique to humans, and thus could be explored in other species. Indeed many features of musicality remain to be further tested and could thereby enlighten some possible interspecific aspects of musicality.

Acknowledgments

We thank O. Bouillet, P. Groué and E. Martin for taking care of the birds. We also thank L. Bouet for helping us with coding the data and Ruth Saint-Hilaire for the revision of the English style in the manuscript.

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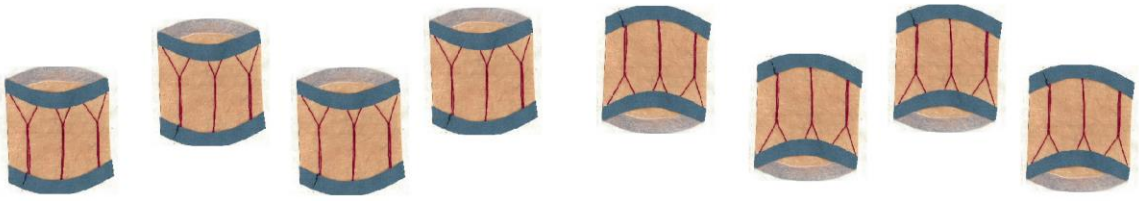
3.2. Production rythmique chez les calopsittes élégantes.....

..... et les corbeaux à gros becs



Spontaneous tempo production in cockatiels (*Nymphicus hollandicus*) and jungle crows (*Corvus macrorhyncos*): a prerequisite to produce rhythms.

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Acknowledgements

We thank O. Bouillet, P. Groué and E. Martin for taking care of the birds.

Abstract

Musical and rhythmical abilities are poorly documented in non-human animals. Most of the existing studies focused on describing synchronization performances to external rhythms. But studies in humans demonstrated that rhythmical processing (involved in tasks such as rhythm discrimination or synchronization to external rhythm) is dependent of an individual feature: the internal tempo. It is assessed in a spontaneous motor tempo task, where participants produce a motor tempo without any specific instructions nor temporal clue. In non-human animal literature, studies describing spontaneous production of motor tempo without any temporal clue are rare. This study aims to describe and compare the spontaneous motor tempo of two bird species. Data were collected on spontaneous behaviours of cockatiels and jungle crows housed in laboratory. Interval inter beak strokes (ISI) were calculated from sound tracks of videos. The analyses revealed that ISI sequences are non-randomly distributed intervals and that they could be considered as tempos. The analyses also revealed that recorded spontaneous motor tempos seem to be different between individuals within a same species. Moreover, the 2 bird species display significantly

different spontaneous tempos. Our results suggest that spontaneous motor tempo, as an expression of internal tempo, is an important feature to consider in non-human animals. As observed in humans, internal tempo could be linked to animal rhythmical abilities.

Keywords: drumming; bird; parrot; beat; music; time

Introduction

Music may be one of the oldest forms of art. The first percussions probably consisted of natural objects barely modified like bamboos, trunks or cranes with which the first humans gave rhythms to their dances (Benardeau et al. 1994). Music, and particularly rhythmical entrainment to external events, are key features of the social life in human culture (McNeill 1997). Almost all human cultures demonstrate music and rhythmical behaviours (Merriam and Merriam 1964), yet in non-human animals, it is not as obvious as in mankind.

This study will contribute to provide novel data in the field of rhythmical processing in poorly documented species and will consider them in an extended theoretical framework.

Optimal rhythmical performances are related to the spontaneous motor tempo in humans.

For many authors, rhythm, the temporal organization of sounds, is a key component of human music (Drake et al. 2000; Godt 2005; Arom 2007; Davies 2012). Rhythm production requires being able to process tempo, i.e. an isochronous sequence of the same event. One of the key tasks to describe one's ability to produce tempo is the spontaneous motor tempo task. The task consists in producing a regular and comfortable tapping task, without any external timer. This ability was initially described in humans, both in children and adults, by Fraisse and colleagues (Fraisse et al. 1954). Several studies showed that spontaneous motor tempo is an individual value, that slows with age and varies across the circadian day (Fraisse et al. 1954; Vanneste et al. 2001; Moussay et al. 2002; Provasi and Bobin-Bègue 2003; Bobin-Bègue and Provasi 2005, 2008; Bobin-Bègue et al. 2006). In adults, spontaneous motor

tempo ranges from 300 ms to 800 ms (200 to 75 bpm), with a mean value around 600 ms (100 bpm). In other timing tasks (such as synchronization or discrimination tasks), rhythmical performances follow a U-shape function, reaching its lowest (i.e. best performance) when the external tempo is equal to the spontaneous motor tempo (Drake et al. 2000). For each individual, the closer to the spontaneous motor tempo of the individual is the external tempo, the better is the synchronization performance, whatever one's age and musical expertise (Gérard and Rosenfeld 1995; van Noorden and Moelants 1999; Provasi and Bobin-Bègue 2003; Bobin-Bègue and Provasi 2008). Moreover, spontaneous motor tempo is a very striking ability in mankind since it is observed at a very early stage in human development (Thelen 1979, 1981; Provasi et al. 2014). Thus, the spontaneous motor tempo appears to be an important feature to describe timing abilities (Drake and Botte 1993), such as synchronization to external events and rhythmical behaviours involved in musical behaviours and in consecutive prosocial behaviours (see for examples: Cirelli et al 2018; Franek, et al 2014; Kuribayashi and Nittono 2014; Large and Palmer 2002; Palmer 1997). Conversely, the ability to spontaneously produce a tempo (a simple form of rhythm), is a necessary ability to access to more complex rhythmical production, and allows the synchronization to external physical or social event. Thus, spontaneous motor tempo production could be considered as a pre-requisite behaviour to perform rhythmical tasks.

Although rhythmical performances and spontaneous motor tempos are well described in humans (for reviews, see for example Provasi et al 2014 and Repp and Su 2013), few results support the existence of rhythmical and motor tempo abilities in non-human animals and even less data support the existence of spontaneous motor tempo in non-human animals. Collecting data on spontaneous motor tempo abilities across a wide variety of species would shed light on the evolution of timing abilities, rhythmical abilities and musical abilities.

Rhythmical abilities in animals

There is evidence that a few species are able to synchronize to external rhythmical auditory stimulation or music. Studies conducted with apes and monkeys, who are phylogenetically very close to humans, provide contrasted results. On one hand, some apes spontaneously display drumming behaviour. For example, studies describe wild chimpanzees (*Pan troglodytes*) hitting the buttress of trees (Arcadi et al. 1998), and chest beating (Schaller

1963) or hand clapping in wild gorillas (*Gorilla gorilla gorilla* and *Gorilla beringei beringei*) (Kalan and Rainey 2009). Yet the regularity of these strokes was not analysed in the chimpanzees nor the gorillas, thus they may not follow any tempo. Another research described that Barney, a captive male chimpanzee, spontaneously displayed a bimanual tempo, sharing structures and features of human musical drumming (Dufour et al. 2015). On the other hand, a complementary study in Barney's colony found no other rhythmical episode that could match the criteria of human musical production (Dufour et al. 2017). Furthermore, the few studies conducted on rhythm entrainment in primates are not convincing, since apes and monkeys need a very long training (until one year) before being able to keep the beat, and some of them do not, even after this extensive training (Zarco et al. 2009; Hattori et al. 2013). Additionally, when rhythmical entrainment is obtained, non-human primates perform with less accuracy and less regularity than humans (Zarco et al. 2009), although adding a spatial component to a visuospatial task seems to help them to better perceive and maintain rhythms of different paces (García-Garibay et al. 2016). Especially, in a spontaneous motor synchronization task, chimpanzees did not perform as well as humans, although they were trained during one year and the task and the apparatus were familiar to them (Hattori et al. 2013). Thus, up to now, available data suggest that the rhythmical abilities of non-human primates are limited.

The inconstancy of this capacity could be related to their low vocal learning abilities: the evidence of complex vocalization learning is very weak in non-human primates (Janik and Slater 1997). Schusterman (2008) describes vocal learning as the ability to modify one's vocal production depending on the external auditory information. For Watanabe et al. (2009), this feature would be related to musical sensitivity, i.e. a musical stimulus would mainly be reinforcing in species that have to learn complex auditory stimulations during their ontogenesis (Watanabe et al. 2009). Vocal learning would also be a pre-requisite to rhythm entrainment as proposed in the vocal learning and synchronization hypothesis (Patel 2010): entrainment to a musical beat would rely on a strong relationship between brain auditory and motor circuits.

As it happens, among vocal learners, several species demonstrate rhythmical abilities such as rhythms and tempo discrimination, tempo production and rhythmical entrainment or tempo synchronization. For example, one sea lion (*Zalophus californianus*) displayed rhythm entrainment following a training phase (Cook et al. 2013). Whether sea lions are

vocal learners or not is still discussed: it was first said that there was little evidence of learnt vocalizations in that species (Peterson and Bartholomew 1969), yet a more recent study reveals that there is increasing evidence suggesting their ability of vocal learning (Reichmuth and Casey 2014). Asian elephants (*Elephas maximus*) are also capable of rhythm entrainment (Schachner et al. 2009). More quantitative and convincing evidence could be find in vocal learner birds. Concerning perceptual abilities, starlings can discriminate rhythmic from arrhythmic patterns (Hulse et al. 1984), zebra finches (*Taeniopygia guttata*) and budgerigars (*Melopsittacus undulatus*) distinguish regular from irregular pulse strings (ten Cate et al. 2016). More specifically, synchronization performances were studied in budgerigars (*Melopsittacus undulatus*), which synchronize themselves with a metronome by pecking a key (Hasegawa et al. 2011), and six psittaciforme species can spontaneously keep the beat while they dance through a large range of tempos (Fitch 2009; Patel et al. 2009; Schachner et al. 2009). Thus, synchronization to an external tempo is easier to elicit in vocal learner birds than in non-vocal learner birds. In humans, synchronization to external tempo does not require any training and is even spontaneous, even with no explicit instructions, in infants, children and adults (Provasi and Bobin-Bègue 2003; Bobin-Bègue et al. 2006; Bobin-Bègue and Provasi 2008; Peckel et al. 2014).

According to Patel et al. (2009), synchronization abilities could have similar neurobiological foundations in humans and birds. In humans, the connections between auditory and motor planning brain structures would be stronger than in non-human primates, because they are capable of vocal learning (Patel and Iversen 2014). Actually, a coupling between vocal and motor development appears even before birth in humans (from the 12th week of gestation) (de Vries et al. 1985) ; this coordination between vocal and motor systems allows babies to develop the future speech gestures in adults (Iverson 2010). As for songbirds and parrots, the nuclei of their neurobiological substrates for vocal control and learning projects onto the vocal motoneurons (Petkov and Jarvis 2012).

The pending question is whether vocal learner species demonstrate the same synchronization performance features as humans, i. e. whether their synchronization performances are better when the external tempo is close to their spontaneous motor tempo than when it is distant from it, as suggested by the results of the previously mentioned studies of Drake et al. (2000), van Noorden et al. (1999) and Bobin-Bègue and Provasi (2008).

However, spontaneous motor tempo behaviours are rarely evidenced in non-human animal studies, even in birds. Yet, among vocal learners, several spontaneous beat productions have been evidenced. For example, one Asian elephant produced a stable beat on a musical instrument, but the task was not a spontaneous motor task since the elephant was trained to strike two bass drums in alternation (Patel and Iversen 2006). Among vocal learner birds, one study described tap dancing in a complex courtship display in blue capped cordon bleus (*Uraeginthus cyanocephalus*) (Ota et al 2015), and another one evidenced that male Java sparrows (*Lonchura oryzivora*) coordinate their bill-click sounds with the syntax of their own song-note sequences (Soma and Mori 2015): this suggests that those species are able to display spontaneous motor tempo. Wild palm cockatoos (*Probosciger aterrimus*) can create tools with which they drum on hollow trees (Wood 1984), with individual styles, performing regular beat production and sharing thus key rudiments of human instrumental music (Heinsohn et al. 2017). Thus very sparse data is available in non-human animals to consider spontaneous motor tempo behaviour as a prerequisite to rhythmical abilities, whether the species is a vocal learner or not. The gradual audio-motor evolution hypothesis suggests that humans only partially share with other primates the ability of rhythmic entrainment (Merchant and Honing 2014). This hypothesis is interesting to consider as it proposes that rhythmical abilities gradually evolved in animals, partially sharing some features of time processing. The limits of this hypothesis are that the focus is on primates and that the spontaneous motor tempo is not considered as a key feature of more general rhythmical abilities. We propose that the abilities to perform spontaneous motor tempo and its features (mean and variability) could contribute to explain the evolution of rhythmical abilities in animals. To this aim, data should thus be collected in various species.

The current study

Cockatiels are cacatuidae, like palm cockatoos, and belong to the Psittaciforme order. Jungle crows are corvids and belong to the Passeriforme order. Both species are capable of vocal learning and are known to share some complex cognitive skills with primates. In our laboratories, cockatiels and jungle crows perform spontaneous drumming sequences.

Like in other vocal learners such as one elephant (Patel and Iversen 2006), java sparrows (Soma and Mori 2015), blue capped cordon bleus (Ota et al. 2015) and palm cockatoos

(Heinsohn et al. 2017), we expect that those bird species would share some features of human music and display regular beats, as suggested in the vocal learning and rhythmic synchronization hypothesis. Thus, our focus is to describe spontaneous motor tempo as an important ability to support rhythmical performances in non-human animals: the specific aim of this study is to explore spontaneous motor tempo production in cockatiels (*Nymphicus hollandicus*) and jungle crows (*Corvus macrorhynchos*) by analysing spontaneous drumming sequences (without any tools, directly on surface/object). After a general description of recorded sequences, the analysis of inter beak strokes intervals of sequences will allow us to provide a description of individual drumming: median of inter stroke intervals and their variability. Those features will allow us to test the following hypotheses:

1. We suggest that the spontaneous drumming sequences of the individuals display sufficiently regular intervals so that they can be assimilated to spontaneous motor tempo in humans and thus could be considered as a motor expression of the individual internal tempo.

If so,

2. We expect that individual spontaneous motor tempos differ between each individual of the same species, as is the case in humans.
3. We propose that the spontaneous motor tempo in cockatiels is different from the spontaneous motor tempo in jungle crows.

Materials and methods

Subjects and housing conditions

For the cockatiels, drumming sequence were recorded in the Laboratoire Éthologie Cognition Développement (LECD) in Nanterre University (France) with thirteen birds, six females and seven males. The cockatiels were housed in an indoor aviary with no window. The temperature was 23°C and the light was on from 9 am to 9 pm. Three stainless steel work benches (155*55*84 cm) were located on the left wall and there were two big perches in the middle of the room. Toys, cardboards and two triangle suspended perches were also

available. Birds were feed ad libitum with, depending on the period, either nutribirds G14 for large parakeets, either seed Deli Nature for large parakeets, various fruits and vegetables, aniseed sand and water.

For the jungle crows, drumming sequence were recorded in the Centre for Advanced Research on Logic and Sensibility, in the department of Psychology of Keio University (Japan), with seven birds, four females and three males. All the crows had been caught in the wild after becoming sub-adults, in Tokyo and neighbour areas, and then housed in individual cages (76cm*48cm*54cm) within the same room in the laboratory. The light was on from 8 am to 11 pm.

Both cockatiels and jungle crows were adults when the rhythms were recorded.

Drumming recordings

As the drumming sequences were not frequent in cockatiels, we analysed each drumming observed in the aviary when the video camera was on. Thereby, our drumming observations run from October 2016 to December 2018.

In order to increase our data, we also put a wide angle camera (@ XPRO2, TecTecTec) in the cockatiels' aviary for three months, from mid November 2018 to mid December 2018 and in April and May 2019. The camera recorded daily observations from the moment the light was on until the light was off in the aviary (i. e. from 9 am to 9 pm) five days a week. Cockatiels being quite destructive birds, a small Plexiglas box was constructed to protect the camera from their beak.

Regarding the jungle crows, for the purpose of another experiment held in November and December 2017, every morning, one bird was taken to an outdoor aviary (2,7m*1,5m*1,6m) and filmed so as his or her behaviour could be analysed later; this is when the drumming sequences were recorded.

Coding and analysis

All the audiograms exported from the videos were coded by the same experimenter. One drumming sequence consisted, for both species, of several gathered beak strokes (see Figure 1).One group of drumming sequences is named an episode.

The drumming episodes lasting less than 5 seconds were not taking into account in the study. The audiogram of each kept drumming episode was then analysed with the software Audacity.

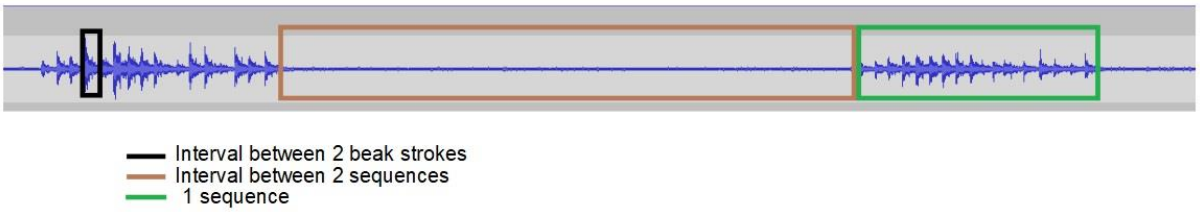

Figure 1: one example of interval between beak strokes, interval between sequences and sequence (bird: Hermès)

The following information was collected per bird:

1. intervals between beak strokes (noted ISI)
2. intervals between sequences
3. number of beak strokes per sequence

Statistical analyses were conducted with Statistica 13.4.0.14.

Results

27 drumming episodes were analysed, 16 for the cockatiels and 11 for the jungle crows. 5 male cockatiels (Hermès, Odin, Eole, Seth and Bahloo) and 2 female crows (Kartikeya and Myrath) drummed, using different supports to perform their drumming (for more details on drumming sequences, see Table 1).

Table 1 : Date, bird and support used for drumming

Cockatiels			Jungle crows		
Recording date	Bird's name	Support	Recording date	Bird's name[1]	Support
21 10 2016	Hermes	Cardboard	05 12 2017	Kartikeya	perch
06 12 2016	Odin	Wall	05 12 2017	Kartikeya	perch
30 12 2017	Odin	cardboard roll	05 12 2017	Kartikeya	perch
30 11 2018	Eole+	cardboard roll	05 12 2017	Kartikeya	perch
22 11 2018	Seth	cardboard roll	05 12 2017	Kartikeya	perch

1 For easy reading and comprehension, we changed the name of jungle crow birds: the original name of Kartikeya is 'fY' and the one of Myrath is 'vf'.

03 12 2018	Odin	cardboard	05 12 2017	Kartikeya	perch
05 12 2018	Odin	cardboard roll	05 12 2017	Kartikeya	perch
13 12 2018	Hermes	cardboard roll	05 12 2017	Kartikeya	perch
14 12 2018	Odin	cardboard roll	05 12 2017	Kartikeya	perch
02 05 2019	Hermes	Cardboard roll	14 12 2017	Myrath	perch
10 05 2019	Hermes	cardboard roll	14 12 2017	Myrath	perch
13 05 2019	Odin	cardboard			
14 05 2019	Odin	cardboard			
25 05 2019	Hermes	cardboard			
28 10 2016	Bahloo	cardboard roll			
2016	Odin	wall			

Many of the cockatiels drumming episodes were recorded by the camera protected by a Plexiglas box, and unfortunately, because of the surrounding noise and the Plexiglas box, only few of the drumming episodes recorded were workable (for example for Eole, none was workable). Here, we present the results of the analysis conducted on the workable episodes.

Descriptives analyses of beak strokes sequences

Table 2 reports the key features of each sequence of beak strokes for cockatiels and jungle crows.

Table 2. Descriptive analyses per birds for the different variables

Name	Species	Number of sequences	Number of ISI	ISI mean (SD)	ISI median (coefficient of variation*)	ISI number mean /sequence (SD)	Sequence Duration mean (SD)	Inter Sequence Interval mean (SD)
Bahloo	Cock	28	202	0.079 (0.02)	0.076 (0.234)	6.875 (2.532)	3.847 (0.188)	3.5 (1.402)
Hermes	Cock	5	69	0.076 (0.013)	0.075 (0.144)	15 (3.606)	5.126 (0.077)	4.281 (0.62)
Odin	Cock	73	520	0.083 (0.08)	0.075 (0.219)	7.275 (3.658)	3.583 (1.156)	1.192 (2.148)
Seth	Cock	5	28	0.17 (0.062)	0.156 (0.41)	3.485 (0.77)	3.217 (0.249)	2.301 (0.72)
Kartikeya	Crow	34	82	0.204 (0.037)	0.197 (0.204)	1.382 (0.907)	2.28 (0.586)	1.382 (0.907)

Intervals between sequences per bird

The intervals between sequences (see Figure 2) show different values according to the individuals of the same species. In cockatiels, the intervals between sequences ran on average from 1.192 seconds to 4.281 seconds, i.e. on average 3.500 seconds for Bahloo, 4.281 seconds for Hermes, 1.192 seconds for Odin and 2.301 seconds for Seth. Only one jungle crow produced workable intervals between sequences, thereby we do not know whether it also varies between the two species. In jungle crows, on average, the interval between sequences was 1.382 seconds for Kartikeya.

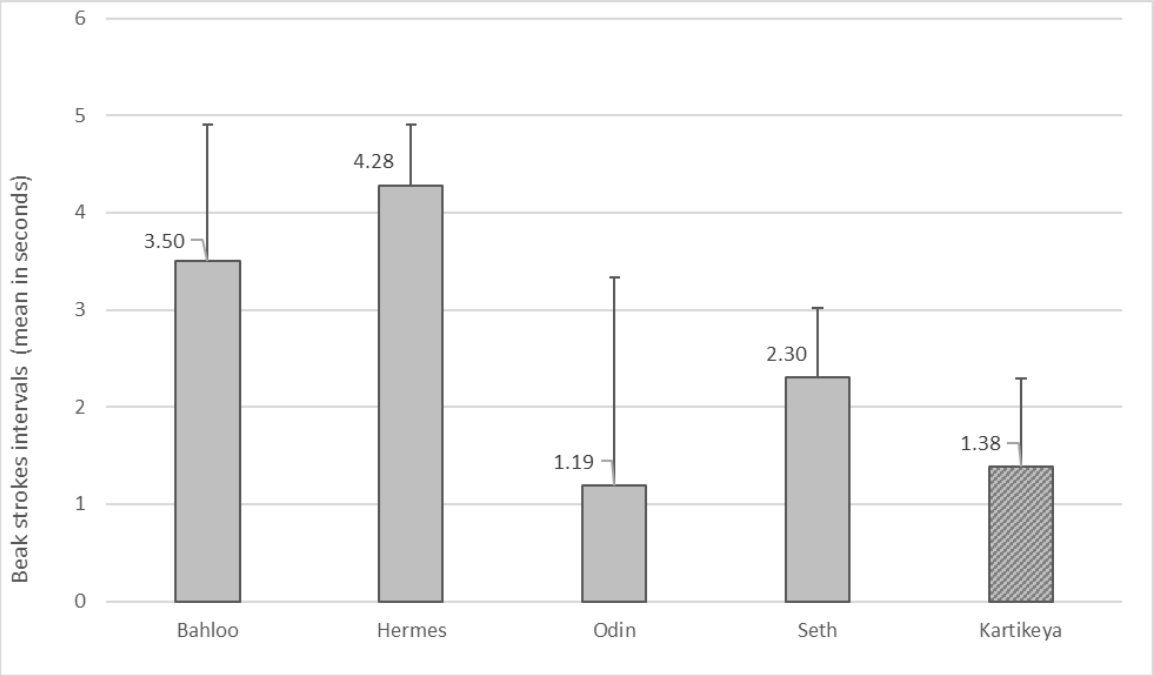

Figure 2. Mean of inter beak strokes intervals between sequences per bird (in seconds)

Number of beak strokes per sequence per bird

The number of beak strokes per sequences (See Figure 3) seems to vary according to the individuals of the same species, but also between the two species. In cockatiels, the number of beak strokes per sequence ran on average from 3.485 to 15, i. e. on average 6.875 for Bahloo, 15 for Hermes, 7.275 for Odin and 3.485 for Seth. In jungle crows, the number of beak strokes per sequence ran on average from 1.382 to 2, i. e. on average 1.382 for Kartikeya and 2 for Myrath.

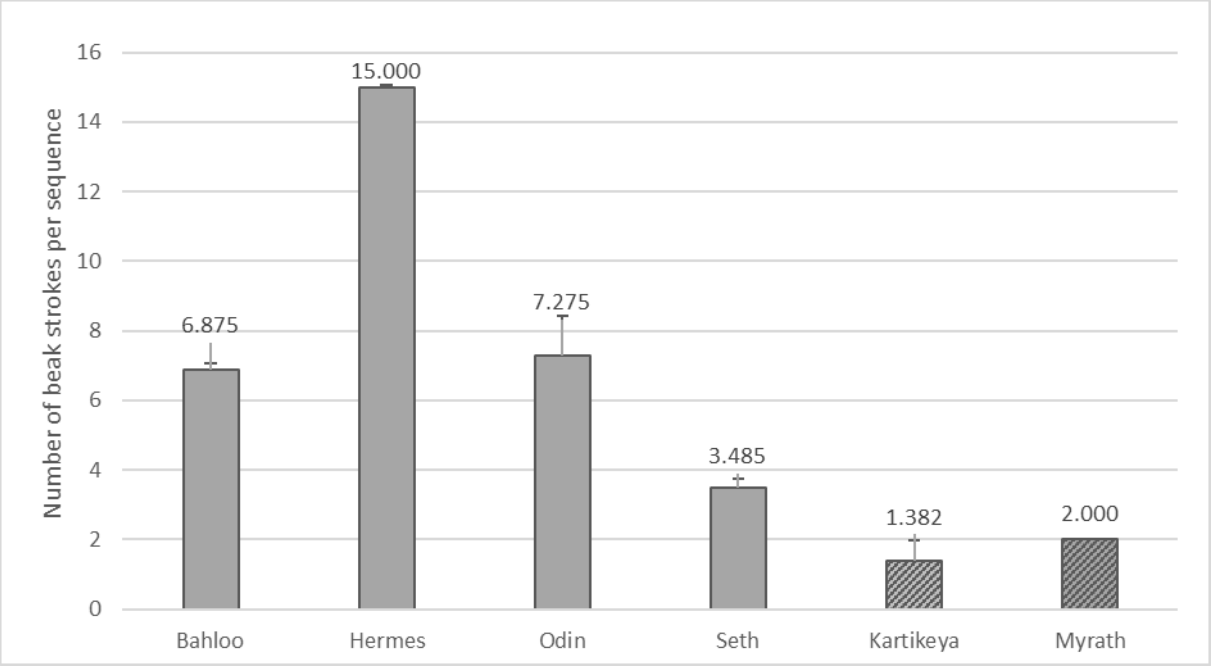

Figure 3. Number of beak strokes per sequence per bird (mean)

Inter-Strokes Intervals (ISI) analyses

Distribution of the inter-strokes intervals

To explore the hypothesis that cockatiels and jungle crows can display a tempo, each distribution of inter-strokes intervals was analysed (see Figure 4).

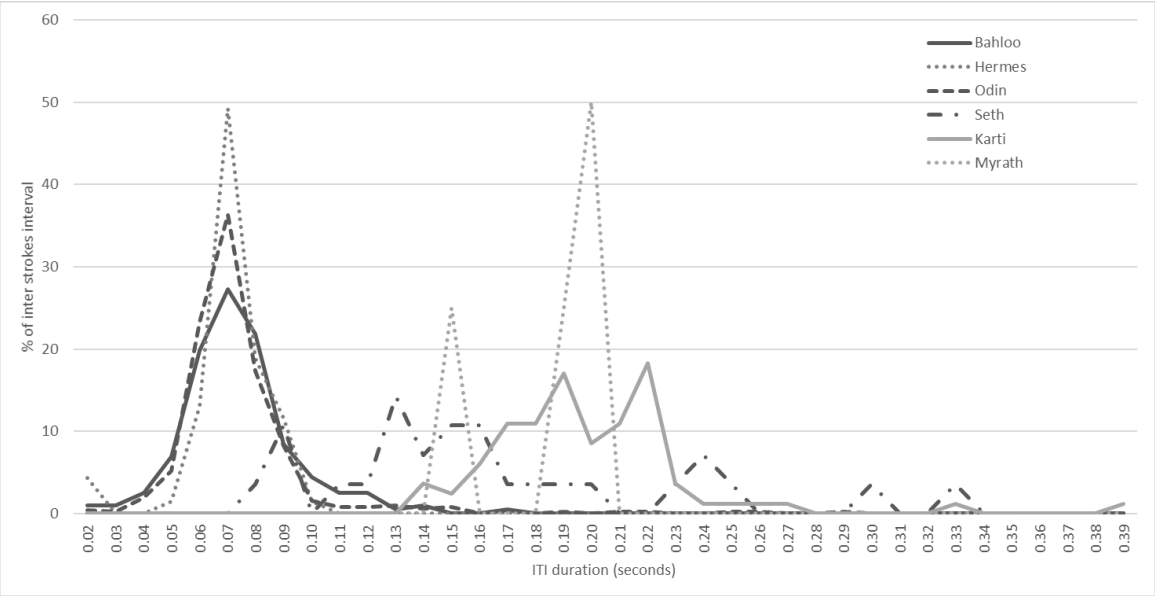

Figure 4. Inter-strokes intervals distribution per individual

To analyse more precisely ISI distribution for each individual, tests of normality were conducted on all ISI for each individual (Table 3). All ISI distributions were significantly different from a normal distribution according to the Shapiro-Wilk W test.

Table 3: Shapiro-Wilk W tests of normality of inter-strokes interval for each individual

Bird's name	Number of strokes	max D	W	P
Bahloo	202	0.118603	0.927444	0.000000
Hermes	69	0.205694	0.827112	0.000000
Odin	520	0.349844	0.148788	0.000000
Seth	28	0.149716	0.923139	0.041497[a]
Kartikeya	82	0.133004	0.842486	0.000000
Myrath	4	0.384211	0.753577	0.041697

[a] the distribution of beak strokes significantly fits a normal distribution.

As the theoretical goal of this study is to find clues suggesting that vocal learners birds and humans share some tempo processing features, we conducted the same analyses of normality with already published data (see Table 4, Bobin-Bègue and Provasi 2008) of 34 3-years-old children (14 girls). The task was a spontaneous unimanual motor tempo task, before which the children watched an adult finger-tapping and were then said "It is your turn". Only 6 children display intertap intervals that fit a normal distribution.

Table 4: tests of normality in 3-years-old children spontaneous motor task

Participant	N	max D	W	p
3F01	30	0.38763837	0.424403	0.000000
3F02	28	0.163500974	0.771035	0.000034
3F03	29	0.261081118	0.576056	0.000000
3F04	28	0.36568869	0.581713	0.000000
3F05	30	0.0716516674	0.963334	0.375807[b]
3F06	30	0.345057634	0.463290	0.000000
3F07	29	0.341534531	0.392438	0.000000
3F08	24	0.231105576	0.739312	0.000035
3F09	28	0.252807749	0.587978	0.000000
3F10	30	0.208925982	0.767375	0.000018
3F11	30	0.301417749	0.552720	0.000000
3F12	29	0.218072992	0.859141	0.001179
3F13	29	0.104137025	0.961132	0.350422[b]
3F14	26	0.152354083	0.930137	0.078078[b]
3G01	30	0.181211593	0.907128	0.012604
3G02	28	0.24276936	0.747212	0.000014
3G03	20	0.253472393	0.651605	0.000011
3G04	30	0.251903881	0.820015	0.000155
3G05	30	0.249634038	0.547186	0.000000
3G06	30	0.249591913	0.684798	0.000001
3G07	30	0.307466947	0.570568	0.000000
3G08	30	0.118541241	0.969088	0.514543[b]
3G09	30	0.111521659	0.976766	0.734619[b]
3G10	28	0.283791017	0.581383	0.000000
3G11	27	0.257315696	0.798652	0.000130
3G12	30	0.240201897	0.619197	0.000000
3G13	30	0.153776145	0.796630	0.000057
3G14	30	0.159929452	0.732514	0.000005
3G15	30	0.176702942	0.814109	0.000120
3G16	30	0.215006124	0.834796	0.000303
3G17	30	0.26065158	0.754609	0.000011
3G18	29	0.246913428	0.606855	0.000000
3G19	30	0.132287248	0.872254	0.001881
3G20*	29	0.127314832	0.961202	0.351799[b]

[b] the distribution of taps significantly fits a normal distribution.

If ISI in a sequence are randomly timed, then ISI should follow an exponential distribution. Thus, we conducted a Kolmogorov-Smirnov test on each of the 18 sequences that counted more than 12 ISI. None of the analysed sequences are random sequence of ISI (Table 5).

Table 5. Kolmogorov-Smirnov test for fitting exponential distribution of drumming sequence

Bird's drumming sequence	Kolmogorov-Smirnov test	
Bahloo_09	d = 0.51490	p < 0.01
Bahloo_15	d = 0.53346	p < 0.01
Hermes_02	d = 0.55499	p < 0.01
Hermes_03	d = 0.58728	p < 0.01
Hermes_04	d = 0.58039	p < 0.01
Hermes_05	d = 0.38695	p < 0.01
Odin_24	d = 0.51264	p < 0.01
Odin_25	d = 0.44821	p < 0.01
Odin_30	d = 0.48018	p < 0.01
Odin_31	d = 0.53859	p < 0.01
Odin_32	d = 0.46288	p < 0.01
Odin_35	d = 0.55376	p < 0.01
Odin_37	d = 0.51766	p < 0.01
Odin_40	d = 0.44629	p < 0.01
Odin_41	d = 0.52384	p < 0.01
Odin_42	d = 0.48055	p < 0.01
Odin_46	d = 0.54047	p < 0.01
Odin_53	d = 0.57720	p < 0.01

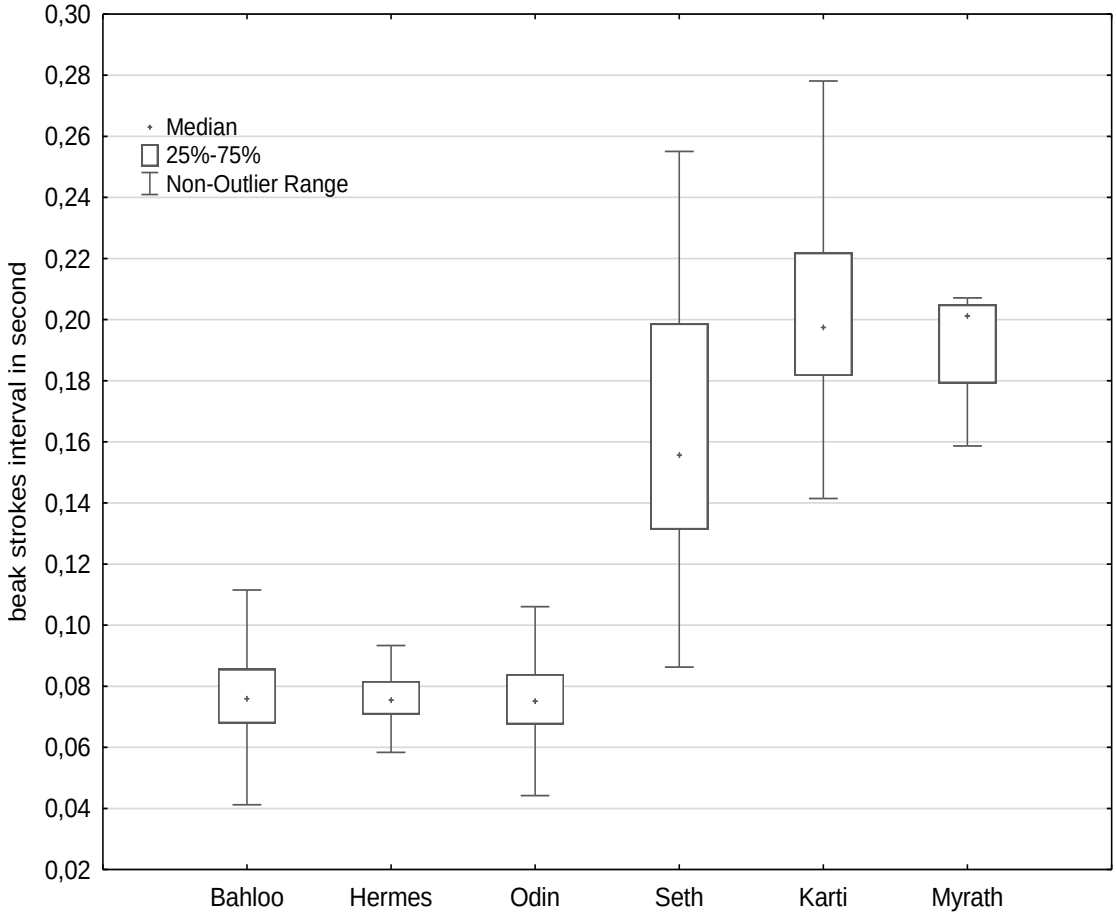

Figure 5. Median, quartiles and non-outlier range of the ISI per birds (in seconds)

Inter-strokes intervals

The median of intervals between beak strokes are similar between the individuals of the same species (see Figure 5). In cockatiels, 3 out of 4 medians of intervals between beak strokes are almost equal (0.075 and 0.076 seconds for Bahloo, Hermes and Odin) and the 4th one produced longer inter-strokes intervals (0.156 seconds for Seth). In jungle crows, median of intervals between beak strokes are higher than in cockatiels (0.197 seconds for Kartikeya and 0.201 seconds for Myrath).

The 3 cockatiels that produce similar values of inter-strokes intervals show a similar variability of intervals. Their variability is around 20% of the interval (respectively: Bahloo 23.4%, Hermes 14.4% and Odin 21.9%). The 4th one, Seth, displays a more important dispersion of the interstroke intervals (Seth 41.0%). In jungle crows, only the beak strokes of Kartikeya are considered as Myrath only displayed 4 intervals. The inter-strokes intervals variability of Kartikeya (20.4%) is similar to those of the 3 cockatiels. Those values are similar to spontaneous motor tempo coefficient of variation in 3-years-old-children (Q1-Q3 range: 16.5%-32.8%; median: 24.6%) (Bobin-Bègue and Provasi 2008).

Non parametric analyses were conducted on mean and coefficient of variation of ISI for each sequence, in function of individuals and species.

The overall ISI median for cockatiels is 0.075147. A median test revealed that ISI median are significantly different between cockatiels [Chi-Square = 6.872566; df = 3; p = .0761]: spontaneous motor tempos of drumming are different between cockatiels in our recordings. This result was confirmed by a Kruskal-Wallis ANOVA by Ranks on the same observation [H(3; N = 111) = 15.80617; p =.0012].

The same analyses were conducted on coefficient of variation (Overall Median = 14.8524) and revealed no significant differences between cockatiels [Chi-Square = 6.948111; df = 3 p = .0736]. This result was confirmed by a Kruskal-Wallis ANOVA by Ranks [H(3; N = 111) = 5.333707; p =.1489].

The median test conducted in jungle crows sequences revealed that ISI median (0.195782) were not significantly different between the 2 individuals [Chi-Square = 2,117647; df = 1 p = ,1456], confirmed by a Kruskal-Wallis test [H(1; N = 36) = 0.2337043; p = .6288].

The median test showed that ISI coefficient of variations (median = 7.07000) revealed no significant differences between the jungle crows [Chi-Square = 1.109694; df = 1 p = ,2921] (Kruskal-Wallis ANOVA by Ranks: [H(1; N = 29) = 0,5142857; p = .4733])

Those results should be considered in light of very small quantity of data recorded for Myrath.

The median test conducted on sequence ISI mean revealed that the spontaneous motor tempo of drumming are significantly different in cockatiels and in jungle crows [Chi-Square = 48.32877; df = 1; p = .0000]. Kruskal-Wallis ANOVA by Ranks confirmed this difference [H(1, N = 147) = 76.76158; p = .0000].

The median test on coefficient of variation revealed a significant difference between the 2 species of birds [Chi-Square = 5.262504; df = 1; p = .0218] confirmed by a Kruskal-Wallis ANOVA by Ranks [H(1, N = 140) = 14.97112 ; p = .0001].

Discussion

In this study, we argue, considering the results in humans, that performing a spontaneous motor tempo is a pre-requisite to be able to synchronize to an external tempo and consequently to display some musical behaviour and to facilitate some social behaviours. To this aim, we recorded spontaneous drumming episodes in captive vocal learner birds. Main features of the recorded spontaneous motor drumming episodes were explored and related to features of human spontaneous motor tempos. Overall, the description of the data in the two species suggests that cockatiels and jungle crows are able to produce spontaneously motor tempo without any external temporal clue. Moreover, the distribution of their intervals are similar to the distribution of the intervals observed in humans (3-years-old children). Probably due to our small sample, we did not find any significant differences between the individuals, yet our data suggested that the median of the inter-strokes intervals might be different between the two species of the studies, and different from humans.

Considerations about data: preliminary results to further investigations

Despite some limitations, this study offers preliminary results that constitute an opportunity to support further investigations. The first limitation is the limited data recorded. Recordings of spontaneous motor tempo in Psittaciformes are rare in the scientific literature. The main reason is undoubtedly related to the fact that only a few researchers work on those topics in such species. A previous study investigated spontaneous drumming sequences in wild palm cockatoos (Heinsohn et al. 2017). Data collection ran on 6 months periods during 6 consecutive years (total: 36 months); during this long period, researchers collected 2 to 33 sequences per individual (total: 18 wild males).They totalized 131 sequences of 10 intervals each on average. In this study, we totalized 201 sequences (165 in cockatiels) corresponding to 805 inter-strokes intervals. Data presented in this study are thus quantitatively similar to those of Heinsohn et al. (2017). It should be mentioned, as it should also be the case in the palm cockatoos study, that drumming behaviours are more numerous than those recorded and analysed. So even if we could only conduct limited analyses, they are informative enough to justify further studies, with more quantitative data.

Another limitation to consider is linked to the conditions of recording. As we analysed all drumming sequences recorded, it should also be underlined that the conditions were not controlled and that the birds were recorded under different conditions. Another point to consider is the recording conditions for the two species: the cockatiels were recorded in their everyday aviary, while the jungle crows were recorded in an outside and unusual aviary in which they were separated from their conspecifics. Nevertheless, all the recorded sequences were produced spontaneously by the individuals, constituting the strength of these data considering our theoretical framework.

Before interpreting our results, we propose to consider some aspects of this rhythmical behaviour. The repeated and quite frequent nature of those drumming sequences could remind of a stereotypic behaviour. Yet, this seems very unlikely, especially for the cockatiels. Indeed, the drumming sequences were not correlated to any stressful context nor fear behaviour. These drumming sequences may rather be linked to courtship behaviours, as they were observed only in males, and mainly during the breeding period (Le Covec et al.

2019). We could thus consider that beak drumming in cockatiels is a natural and spontaneous behaviour.

Hereafter, we discuss all results at best with these considerations in mind.

Features of the spontaneous motor tempo displayed by the birds

The coefficients of variation of inter-strokes intervals are similar to spontaneous motor tempo coefficients of variation in 3-years-old-children. Thus, spontaneous drumming sequences are regular enough to be considered as tempos. In addition, the distribution of inter-strokes intervals does not fit a normal distribution, nor a random distribution. Both suggest the existence of a specific mechanism that could be an analogous of the internal tempo described in the human literature.

As cockatiels and jungle crows are able to produce spontaneous motor tempos, we propose that they have the necessary underlying mechanisms to spontaneously produce regular intervals as it is observed in humans. Considering our theoretical framework, regarding which the ability to produce a spontaneous motor tempo is necessary to synchronize to external tempo, and considering the gradual audio motor evolution hypothesis, those two species are thus good candidates to test whether they are able to synchronize to external tempos. Then, as suggested by Merchant and Honing (2014), the duration of the possible training period and performances will provide additional data to extend this hypothesis to non-primate animals.

As recalled above, for many authors, the temporal organization of sounds is a key component of human music (Drake et al. 2000; Godt 2005; Arom 2007; Davies 2012). Combined to another study showing that the cockatiels produce sounds intentionally, and that they can use a tool in order to achieve their goal (Le Covec et al. 2019), those results support the idea that those birds would display some protomusical behaviour.

Intraspecific differences in the spontaneous motor tempo

Our second hypothesis concerned individual values of spontaneous motor tempos. Our birds showed intraspecific differences regarding the intervals between beak strokes, the intervals between sequences and the number of beak strokes per sequences. However,

these differences are not significant, which may be due to the small number of individuals. If confirmed, the observed intraspecific differences could be related to the drumming of palm cockatoos, which are known for their creation of tools with which they drum on hollow trees (Wood 1984) with individual styles (Heinsohn et al. 2017). But it could also be related to the individual internal tempo that has been evidenced in mankind (Drake et al. 2000) which therefore would not be a human specificity: the tempo median value displayed by each bird could reveal his or her internal tempo.

In 1935, Alexander postulated the existence of an accurate physiological chronometer, suggesting that the regular flashing of fireflies could be related to physiological specificities (Alexander 1935). In humans, it has been evidenced that the individual tempo slows down with age (Drake et al. 2000; Vanneste et al. 2001) and is dependant of internal and external factors such as circadian clock, external tempo or body temperature (Hoagland and Perkins 1935; Boltz 1994; Semjen et al. 1998; Wearden et al. 1999; Moussay et al. 2002; Provasi and Bobin-Bègue 2003; Kuriyama et al. 2005; Bobin-Bègue et al. 2006). Therefore, it is credible that physiological parameters of each individual (heart rate for instance) would be involved in the pace of this individual tempo.

Interspecific differences in the spontaneous motor tempo

Regarding interspecific differences, we can note that only males drummed in cockatiels and only females drummed in jungle crows. Nevertheless, due to our very small data sample, we cannot generalize this observation.

Our birds showed significant interspecific differences regarding the intervals between beak strokes and the number of beak strokes per sequence; in particular, the intervals between beak strokes are shorter in cockatiels than in jungle crows (i.e. faster tempos in cockatiels than in jungle crows). This interspecific difference regarding the intervals between beak strokes could, once more, remind us of the individual internal tempo and its dependency to physiological parameters. We could postulate that cockatiels, because they are smaller than crows, have a faster heart rate and thus display smaller intervals between two strokes within one sequence. As it happens, comparing heart rate and intervals between strokes in several species, in cockatiels, chimpanzees and human adults, the faster the heart rate is the smaller are the intervals between strokes. This does not, however, apply to palm

cockatoos, for which intervals between strokes are longer than for human adults whereas there heart rate is faster. Yet, palm cockatoos drum with their feet, and although many psittaciformes are known for having a strong zygodactyl foot, they are less skilful with it than with their beak; thereby the drumming sequences they perform would not be representative of their individual tempo, because it would be restrained by the foot use. Moreover, even if the relation between internal tempo and heart rate is credible, other physiological parameters may interact. Specific studies should be conducted to confirm or refute the relation between heart rate and species internal tempo when it could be observed.

Possible functions for the drumming behaviour

Sexual display

Several examples of rhythmic behaviour in non-human animals have been identified as sexual displays, as is the case of American fireflies (*Photinus pyralis*), which are brought together by a system of regular flashing signals (Buck 1988), but also of birds like Java sparrows (Soma and Mori 2015) or blue capped cordon bleu (Ota et al. 2015), whose tap dancing would be a non-vocal sexual acoustic signal. The drumming of palm cockatoos has been suggested to be a sexual display too. Besides, in a previous study, we showed that in the same cockatiels, drumming sequences appeared more during the breeding period than before or after (Le Covec et al. 2019). Those drumming sequences could therefore be a sexual display.

The synchrony and sociality hypothesis

In 1866, Theobald suggested that the rhythmic flashes of insects were induced by the gathering of a large number of insects sharing a small space, which may have generated synchronous emission of flashes “by the force of imitation or sympathy” (Theobald 1866 cited in Buck 1938). More than a century later, Merker and colleagues (2009) explain that, because it allows for an accurate prediction of events in time, perceiving temporally regular pulses could have appeared so as to achieve synchrony (Merker et al. 2009). This can be related to the synchrony and sociality hypothesis for human tempo perception and entrainment. Indeed, we have a behavioural tendency to move to music which has evolved because it allows interpersonal synchrony, and thus induces prosocial consequences that

gives a fitness advantage on individuals living in groups practising music (McNeill 1997; Bowling et al. 2013; Marsh et al. 2013; Cirelli et al. 2014; Peckel et al. 2014). Like humans, Psittaciformes can keep the beat while dancing (Schachner et al. 2009), but they are also gregarious birds. Thus, entraining to a rhythm when dancing could be related to social actions (Fitch 2009): the famous cockatoo Snowball was observed displaying 14 different movements synchronized with the music he heard, which was suggested to be a social behaviour allowing him to interact with his human caretakers (Keehn et al. 2019). Thereby, rhythm production could also be related to this sensitivity to rhythm, and thus to their gregarious nature. As for corvids, their musical and rhythmical abilities remain to be evidenced, yet they live in large and complex societies (Emery 2004). The synchrony and sociality hypothesis therefore deserves to be further studied in those species.

Considering the spontaneous motor tempo as a pre-requisite to rhythmical synchronization performance

Initially, the vocal learning hypothesis postulates that there is a clear distinction between vocal and non vocal learners, and that only vocal learners would show musical and rhythmic abilities (Patel 2010). Yet, to date, the empirical evidence does not fit well with a binary categorical distinction between vocal learning versus non-vocal learning, and between musical and rhythmic abilities versus a total insensitivity to music and rhythm. First, as described above, although contrasted, the results with apes and monkeys did evidence some rhythmical competences (see Arcadi et al. 1998; Dufour et al. 2015; García-Garibay et al 2016; Hattori et al. 2013; Kalan and Rainey 2009; Nagasaka et al 2013; Schaller 1963; Zarco et al. 2009). Besides, other non-vocal learners have displayed limited rhythmical abilities such as rhythmic synchronous flashing, in fireflies (for a review, see Buck 1988), stereotyped structure of the coo, in collared dove (*Streptopelia decaocto*) (Ballintijn and Ten Cate 1999) and meters discrimination, in pigeons (Hagmann and Cook 2010). Vocal learners like zebra finches can also distinguish an isochronous stimulus from an irregular stimulus, but they do not generalize this task over tempo changes, contrary to humans (van der Aa et al. 2015).

Therefore, less categorical assumptions have been hypothesized over the past few years, arguing for a more gradual continuum instead of an absolute jump. For example, Arriaga and Jarvis (2013) offered the “continuum hypothesis”, ranging from non-vocal learners and

limited vocal learners to complex vocal learners, and regarding which the vocal learning feature would not be dichotomous but distributed along a broad spectrum of behavioural and neural traits. Merchant and Honing (2014) proposed a quite similar idea applying to rhythm in their “gradual audiomotor evolution hypothesis”, which suggests that rhythmic entrainment would be gradually developed in primates and peaking in humans.

Conclusion

To our knowledge, we describe here the first case of documented spontaneous tempo production in cockatiels and in corvids. In spite of scarce data, our observations allowed us to describe, in two species, drumming sequences. Those drumming sequences displayed significant interspecific and possible intraspecific differences. Because of the limits of this case, our results must be taken carefully, but we hope that it will pave the way for more studies exploring rhythmic spontaneous production in non-human animals. Indeed, if supported by further investigation, our observations could suggest that some non-human animals may have, like humans, an internal tempo related to physiological mechanisms, and that complex vocal learners, such as psittaciformes and passeriformes, are capable of predictive rhythmic production. They also suggest that musicality would not be unique to humans and that we share several features of musicality with other species.

Ethic statement and authorizations

The cockatiels were housed according to standard conditions approved by the French National authorities. This study is in line with French and European legislation for animals care and was approved by the Ethical Committee for Animal Experimentation Charles Darwin (authorization number #7035 2016093011025283 v2).

The jungle crows were caught in the wild under the permission of the Japan Ministry of the Environment (authorization number #2025575).

Conflict of Interest: The authors declare that they have no conflict of interest.

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Discussion générale

I. Rappels des buts de la thèse

La musique étant difficile à définir comme un tout et se décrivant davantage en termes de caractéristiques distinctes (voir notamment Fitch, 2006 et Ravignani et al., 2014), notre premier objectif (1) était de déterminer quels critères de musique et de musicalité remplissaient les oiseaux. Dans cette optique, ce travail de thèse s'est intéressé à la sensibilité musicale chez deux espèces d'oiseaux, les corbeaux à gros becs et les calopsittes élégantes, pour lesquels nous avons étudié l'aspect perceptif / sensitif de la musique et l'aspect production en interaction avec l'environnement selon trois axes majeurs : l'influence de la musique, les préférences musicales et l'expression sonore et rythmique.

Notre deuxième objectif (2) était d'apporter des éléments qui permettent d'éclairer différentes hypothèses évolutives portant sur l'apparition de la musique au sein de l'espèce humaine. Nous nous sommes intéressés à la musique dans le cadre de la sélection sexuelle (voir Miller, 2000) par l'intermédiaire d'une étude sur la production sonore chez les calopsittes élégantes, dans laquelle nous avons regardé si les mâles étaient plus motivés que les femelles à produire des sons et des rythmes, et plus spécifiquement lors de comportements de parade et pendant la période de reproduction. Nous nous sommes également penchés sur l'hypothèse du jeu comme précurseur de la musique (voir Cross & Morley, 2008) par l'intermédiaire de la même étude, dans laquelle nous nous sommes intéressés aux comportements de jeu d'objets et aux manipulations sonores chez les calopsittes élégantes. Nous avons de plus testé l'hypothèse de la musique comme renforçateur des liens sociaux (voir Freeman, 1998 et Dunbar, 2017) via une recherche portant sur l'influence de la musique chez les calopsittes élégantes et les enfants, dans laquelle nous nous sommes intéressés aux effets positifs de la musique sur les comportements individuels et sociaux. Enfin, nous nous sommes penchés sur l'hypothèse de l'apprentissage vocal comme facilitateur de la musicalité (voir Patel, 2009 et Watanabe et al., 2009) en étudiant la sensibilité musicale des calopsittes élégantes et des corbeaux à gros becs par l'intermédiaire de diverses modalités (leur capacité à être influencés par la musique, à éprouver des préférences musicales et à produire des sons et des rythmes). Nous nous sommes également intéressés à la notion de convergence évolutive entre les humains

et les oiseaux (les calopsittes élégantes et les corbeaux à gros becs) concernant deux traits en particulier : l'apprentissage vocal et la musicalité (voir Fitch, 2006). Nous nous sommes pour cela penchés sur différents éléments de la musicalité humaine (les influences, les préférences et la production sonore et rythmique) afin de déterminer si ces traits étaient partagés avec les oiseaux.

Notre troisième objectif (3) était de proposer des pistes s'inscrivant dans le cadre du bien-être animal. Pour ce faire, nous avons étudié l'influence positive de la musique sur les comportements sociaux et individuels chez les perruches calopsittes, et nous nous sommes penchés sur l'influence positive de la musique sur les comportements individuels et les préférences musicales chez les corbeaux à gros becs. Nous nous sommes également intéressés à la notion de préférences musicales chez les perruches calopsittes en lien avec l'individu et la personnalité, ce afin de préciser l'importance que peut avoir la diffusion d'un stimulus adapté à (ou aux) l'individu(s) ciblé(s). Enfin, nous avons proposé aux calopsittes différents supports sonores, afin de déterminer si cela permettait d'enrichir leur environnement.

II. Les oiseaux sont-ils musiciens ?

1. Quels critères de musicalité nos oiseaux remplissent-ils ?

Nous avons présenté, dans l'introduction générale, les points de vue de différents auteurs proposant plusieurs caractéristiques qui composeraient la musique. Il s'agit maintenant de discuter des critères que remplissent les calopsittes élégantes et les corbeaux à gros bec dans ce travail de thèse.

Arom (2007) a défini plusieurs « universaux musicaux », des caractéristiques de la musique produite par les humains, et suggère d'étudier ces critères au sein du règne animal.

Nos calopsittes remplissent le critère (1), défini comme « la présence d'une intentionnalité pour celui qui agit et pour les membres de sa culture » : dans notre étude portant sur la production sonore, les oiseaux ayant manipulé les objets sonores l'ont fait de

façon répétée et ce sans récompense, ce qui montre une intentionnalité dans leurs actes. Si la manipulation est voulue de la part des oiseaux, le bruit pourrait n'être qu'une conséquence de ce jeu d'objet, et pas un objectif en lui-même. Cependant, le fait que les oiseaux manipulent davantage avec bruit lors de la période de reproduction tend à montrer que lorsqu'ils produisent un son, ils le font de façon intentionnelle. C'est d'autant plus clairement le cas pour Seth qui, à de nombreuses reprises, a posé ou lâché un grelot sur un xylophone : cet oiseau a également essayé la même action avec une graine au lieu du grelot mais n'a pas poursuivi, probablement parce que le résultat était moins sonore. Notre étude portant sur la production rythmique chez les calopsittes élégantes et les corbeaux à gros becs a aussi mis en évidence des comportements de tambourinages spontanés et intentionnels. Ces tambourinages montrent une certaine régularité des intervalles inter-coups de bec, ce qui correspond au critère (3), défini comme « la présence de ratios temporels », soit d'une pulsation basée sur une périodicité invariable.

Les critères (2), soit la notion de processus formel, (la musique serait le résultat d'une convention), (4), défini comme « la présence de symétrie, dans la mesure où la musique serait une recherche d'équilibre », (5) la référence à une échelle musicale, soit des hauteurs contrastives sélectionnées dans le continuum sonore (c'est le cas par exemple de la gamme pentatonique), et (7), qui s'intéresse à la signification attribuée à une production donnée, n'ont pas été mis en évidence dans cette thèse. Le critère (6), qui implique une répartition des rôles dans la production de musique lorsque plus d'un individu est impliqué, n'a pas pu être étudié au cours de ce travail, et ce d'autant moins que lorsqu'ils se posaient sur la paillasse pour manipuler, les oiseaux venaient le plus souvent seuls, et n'étaient pas spécialement suivis par d'autres congénères.

Pour Arom (2007), chaque musique humaine regroupe au minimum deux de ces critères : pour étendre la notion de musique au-delà de l'être humain, il faudrait que ce soit aussi le cas chez d'autres espèces. Les comportements de tambourinages des calopsites élégantes et des corbeaux à gros becs remplissent deux de ces critères, l'intentionnalité et a présence d'une pulsation. Les comportements de production sonore chez les calopsittes élégantes rentrent également dans le cadre du premier critère. Selon Arom (2007), il est donc possible d'étendre la notion de musique chez ces deux espèces.

Pour Watanabe (2013), les comportements artistiques peuvent être étudiés selon trois aspects.

Le premier est l'aspect cognitif, soit la capacité de discrimination : notre étude portant sur les influences de la musique révèle que les oiseaux montrent moins de toilettages (auto ou mutuels), moins de sollicitations de toilettages et moins de déchiquetage de jouets à la diffusion de musique consonante qu'à la diffusion de musique dissonante et dans le silence. Il est donc possible qu'ils prêtent particulièrement attention à la musique consonante et aient tendance à stopper leurs activités habituelles. Nos données révèlent également que deux mâles calopsittes de cette étude, et plus particulièrement un jeune mâle, chantent davantage lorsqu'on leur diffuse de la musique dissonante. S'il est difficile d'interpréter ce résultat, nous pouvons cependant supposer que ces oiseaux font la distinction entre la musique consonante et la musique dissonante.

Le deuxième aspect est celui du plaisir, autrement dit la notion de renforcement : notre étude portant sur les préférence musicales chez les calopsittes révèle qu'en fonction des types de musique proposés, les oiseaux ayant interagi avec le dispositif montrent soit des choix individuels (rock versus musique calme) soit une absence de choix (consonance versus dissonance), ce qui laisse supposer que certains stimuli musicaux sont suffisamment plaisants à leurs oreilles pour qu'à récompense égale ils expriment leur préférence, alors que d'autre stimuli leurs sont indifférents. Ces résultats doivent malgré tout être nuancés dans la mesure où nous n'avons pas pu tester chez ces oiseaux la préférence de la musique par rapport au silence. Cependant, la recherche portant sur la production sonore chez les calopsittes a montré des jeux d'objets sonores répétés, ce qui permet de supposer que manipuler des objets bruyants était plaisant à leurs oreilles. Celle portant sur les influences de la musique révèle une influence positive de la musique sur les comportements. Cet effet renforçateur peut être mis en lien avec la notion subjective d'appréciation artistique : nous pouvons poser l'hypothèse que si la musique a un effet positif sur les comportements des calopsittes, c'est qu'elles l'apprécient et que donc, dans une certaine mesure, elles la trouvent belle, autrement dit elles prendraient plaisir à l'écouter. Dans l'art, la notion de plaisir est souvent liée à celle de beauté (Chatterjee, 2014) : le fait de trouver qu'une œuvre d'art est belle induirait du plaisir (Reber et al., 2004). Chez les corbeaux à gros becs, l'étude portant sur les préférences musicale est cependant moins concluante, en raison du temps

très court qui a été dévolu à cette expérience et des comportements de stress que montrent les individus.

Le troisième aspect est celui de la créativité, que nous avons choisi de définir comme un processus nécessitant d'une part l'originalité (soit la présence d'un élément nouveau ou inhabituel) et d'autre part l'effectivité (Runco & Jaeger, 2012). Les interactions sonores qu'ont montrées les calopsittes en présence des instruments mis à disposition étaient inhabituelles. Mais cette définition s'applique plus particulièrement au comportement de Seth : l'action de poser ou de lâcher un grelot sur le xylophone était inhabituelle et nouvelle, puisque nous n'avions jamais vu aucun des oiseaux utiliser un outil de la sorte ; elle était également effective, puisqu'elle lui a permis de produire des sons. Nous pouvons donc dire que Seth a fait preuve de créativité.

Otsuka et al. (2009) proposent également trois critères permettant d'étudier la musicalité, les deux premiers étant identiques aux deux premiers critères de Watanabe. Le troisième recouvre l'aspect facilitateur/inhibiteur, soit la possibilité d'être influencé positivement ou négativement par la musique. D'une manière générale, notre étude portant sur l'influence de la musique montre que la musique influence le comportement des calopsittes : les oiseaux montrent par exemple moins de comportements de maintenance en musique qu'en silence. Plus spécifiquement, la musique a une influence positive sur les interactions sociales chez ces oiseaux (plus de proximité physique entre les individus et moins d'agressivité).

Enfin, Gupfinger & Kaltenbrunner (2018) ont défini 4 types de projets musicaux impliquant des animaux. Notre recherche portant sur la production sonore chez les calopsittes s'inscrit dans le quatrième type de projet, « *les animaux comme musiciens volontaires* » (soit le plus complexe cognitivement parlant pour les animaux), puisque tout comme dans le projet *metamusic* d'Alien production présenté dans l'article, où des gris du Gabon explorent et jouent de façon sonore avec les outils qui leur sont proposés, les oiseaux de notre étude ont interagi à de nombreuses reprises avec les objets fournis, d'une façon volontaire et sonore, et ce sans être récompensés.

À notre connaissance, notre projet est le premier à explorer d'une façon aussi complète la présence de critères musicaux chez deux espèces non-humaines (voir tableau 1 pour un résumé des critères validés).

Tableau 1 : résumé des critères validés chez les calopsittes élégantes et les corbeaux à gros becs

Auteur(s)	Notion étudiée	Critères	Calopsittes élégantes	Corbeaux à gros becs
Arom	*Musique*	*Intentionnalité*	✓	?
Arom	*Musique*	*Processus formel*	?	?
Arom	*Musique*	*Pulsation*	✓	✓
Arom	*Musique*	*Symétrie*	?	?
Arom	*Musique*	*Échelle de valeurs*	?	?
Arom	*Musique*	*Répartition des rôles*	?	?
Arom	*Musique*	*Signification*	?	?
Watanabe – Otsuka	*Musicalité*	*Discrimination*	✓	x
Watanabe - Otsuka	*Musicalité*	*Plaisir*	?	x
Watanabe	*Musicalité*	*Créativité*	✓	?
Otsuka	*Musicalité*	*Influences*	✓	x

2. Les critères peu explorés

a. Préférence pour la musique au silence ou à tout autre bruit

Nous pouvons supposer que l'un des critères de la musicalité serait la capacité à éprouver des préférences musicales individuelles, mais aussi à préférer, dans un certain nombre de cas, la musique au silence ou à tout autre type de bruit.

Notre étude portant sur les préférences musicales chez les calopsittes élégantes devait au départ étudier la préférence de musique par rapport au silence. En effet, en plus des deux tests effectués, un troisième test a été mis en place, proposant cette fois-ci sur l'écran tactile trois formes au lieu de deux, deux d'entre elles permettant la diffusion de deux types de musique différents (du rap belge versus du black metal) et la troisième ne déclenchant rien : nous souhaitions ainsi déterminer si, à récompense égale, les oiseaux choisiraient d'écouter

la musique ou préféreraient le silence. Ce test a malheureusement été interrompu prématurément en raison d'un manque de motivation des oiseaux, pouvant être lié à divers facteurs (mort de deux oiseaux entre le test 2 et le test 3, ce qui semble avoir beaucoup stressé le reste du groupe, changement de régime alimentaire en raison des deux décès, rendant les récompenses beaucoup moins attractives, et canicule associée à de gros problèmes de ventilation, induisant des températures supérieurs à 30 degrés dans la volière et une certaine apathie chez les oiseaux). Nous n'avons donc pas pu tester la préférence de ces oiseaux entre la musique et le silence. Par ailleurs, plusieurs difficultés matérielles ont compliqué la recherche : un premier écran tactile préalablement utilisé avec les gris du Gabon du laboratoire est tombé en panne dès les premiers essais, et le second écran commandé n'a pas pu être utilisé par les calopsittes qui n'ont jamais réussi à le faire fonctionner malgré leurs efforts pour taper fort et longuement (probablement en raison de la surface de leur bec, moins importante que celle des gris du Gabon). Le bon déroulement de cette recherche dépendait donc de la présence d'un expérimentateur dans la volière ; par conséquent nous n'avons pas pu laisser l'écran seul dans la pièce, comme cela avait été le cas pour les gris du Gabon, afin de voir si les calopsittes déclenchaient la musique en notre absence, sans récompense alimentaire, et ainsi si la musique était en soi une récompense pour les oiseaux.

Notre étude portant sur les préférences musicales chez les corbeaux à gros becs n'a pas montré de différences comportementales ni de changement de zones entre le silence et la diffusion de musique, ce qui suppose qu'ils n'ont pas particulièrement pris plaisir à l'écouter et n'ont pas cherché à s'en rapprocher. Le temps trop court dévolu à cette étude et l'état de stress des oiseaux ne nous permettent pas de conclure quant aux éventuelles préférences des corbeaux. Cette étude comprenait également, parmi les stimuli diffusés, un bruit blanc supposé vérifier que si préférences il y avait, elles portaient bien sur la musique et non sur n'importe quel type de bruit. Il se trouve que ce stimulus est le seul à avoir eu un impact sur le comportement des oiseaux, qui ont passé une majorité de temps dans la zone la plus éloignée du haut-parleur quand il était diffusé. Ce bruit semble donc ne pas leur plaire. Certaines études utilisent d'ailleurs le bruit blanc comme un bruit aversif (Baltissen & Boucsein, 1998 ; Lissek et al., 2005), et nos données montrent qu'en effet, l'utiliser comme un stimulus neutre n'était pas forcément pertinent dans ce cadre.

b. La représentation publique

La notion de représentation publique est également souvent associée à l'art : la production d'art est habituellement une activité sociale, dans laquelle celui qui produit et celui qui reçoit sont deux personnes différentes (Beardsley, 2018) et il y a souvent, dans une performance artistique, une relation importante entre l'artiste et sa communauté, le but étant pour l'artiste d'atteindre son public (Graham, 2005). C'est notamment le cas pour les arts qui sont sujets aux représentations, tels que la danse, le théâtre ou bien sûr la musique.

Nous ne nous sommes que peu intéressés à cette notion de représentation publique de la musicalité au cours de ce travail de thèse. Notre recherche portant sur la production sonore et rythmique montre que d'une manière générale, quand les oiseaux manipulent les objets et produisent des sons, ils le font davantage quand ils sont seuls sur la paillasse qu'en groupe, mais les instruments étant disposés dans la volière, tous les oiseaux voyaient et entendaient nécessairement chacune des manipulations. Nous avons également observé que la production de sons et de tambourinages intervenait majoritairement pendant la période de reproduction ; il pourrait donc s'agir de comportements de parades. Ces comportements pourraient être dus à un changement hormonal : chez certaines espèces, la concentration de glucocorticoïde varie au moment de la période de reproduction (Casagrande et al., 2018) et le niveau de testostérone augmente (Chastel et al., 2005). Ces parades pourraient également être dirigées vers une certaine audience ne participant pas à la performance.

c. Tension / relaxation

La notion de tension/relaxation n'a pas non plus été étudiée ici. Cette notion se réfère à la construction d'une intensité musicale qui finit par se dissoudre ; pour l'auditeur, cela correspond à un moment où la musique crée une tension dont il attend le relâchement. Dans la musique humaine, diverses caractéristiques (le tempo, le timbre, la puissance sonore…) peuvent induire des émotions différentes (Juslin, 1997) : par exemple un son bas, un tempo lent et des accords saccadés induiront une sensation de peur alors qu'un niveau sonore élevé, un tempo rapide et des accords saccadés engendreront des sentiments positifs

(Juslin, 1997). Cette notion de tension/relaxation n'a pas été étudiée au cours de ce travail de thèse.

Chez l'animal non-humain, la mesure des émotions peut se faire par l'intermédiaire de marqueurs physiologiques (par exemple le stress est connu pour augmenter la concentration de cortisol dans le sang, voir Mellama et al., 2006, Hernandez et al., 2010, et un bas niveau basal d'ocytocine pourrait être un marqueur de bien-être, Lansade et al., 2018) et comportementaux (le stress peut engendrer une certaine agitation et de fortes vocalisations, Leidig et al., 2009, Hernandez et al., 2010, tandis que certains états positifs peuvent être indiqués par des comportements de jeu, Jensen & Kyhn, 2000). Quelques études se sont intéressées à l'influence de la musique sur la physiologie des animaux non-humains : la musique déclenche une augmentation de la synthèse de la dopamine dans le cerveau du rat (Sutoo & Akiyama, 2004), et chez les chiens des changements physiologiques bénéfiques qui pourraient impliquer une diminution du stress (Bowman et al., 2017). En nous intéressant à l'influence de la musique sur les comportements, nous nous sommes également, d'une certaine manière, penchés sur les sentiments positifs qui pouvaient en résulter chez ces oiseaux.

Dans ce cadre de tension-relaxation, il serait intéressant d'affiner ces recherches. Des mesures physiologiques et comportementales pourraient par exemple permettre de déterminer si cette tension/relaxation induite par la musique se retrouve chez d'autres animaux que l'être humain. Il a été montré que chez les aras ararauna, la position des plumes et la coloration des joues changeait en fonction du contexte social (Bertin et al., 2018). Nous avons également conduit une étude (voir les annexes pour plus de détails sur l'étude) portant sur les manifestations visuelles et comportementales de différentes émotions (essentiellement la peur et l'attention) chez les calopsittes (mouvements de la crête, déplacements, types de cris, etc.). Les résultats de cette étude pourront peut-être nous permettre d'analyser plus finement le comportement des oiseaux lors de l'écoute de musique, et d'émettre, d'après la fluctuation de la crête, des suppositions sur la fluctuation des émotions que cette écoute pourrait engendrer.

III. Les résultats à la lumière des hypothèses évolutives

1. La sélection sexuelle

L'hypothèse de la sélection sexuelle postule que les traits qui permettent l'attractivité et l'accès au partenaire pour la reproduction devraient être adaptatifs. Dans ce cadre, la musique pourrait avoir évolué car elle améliore le succès reproducteur (Miller, 2000).

Notre étude portant sur l'expression sonore chez les calopsittes élégantes montre que d'une manière générale, les mâles manipulent davantage les objets que les femelles, et d'une façon plus bruyante. Cette manipulation d'objets est particulièrement sonore pendant la période de reproduction. Par ailleurs, ils chantent et tambourinent uniquement pendant cette même période de reproduction, et les mâles ayant montré tout ou partie de ces comportements étaient chacun appariés avec une femelle. Nos résultats vont donc dans le sens d'une production sonore et rythmique utilisée dans le cadre de parades. Cette étude est la première à mettre en évidence ce type de comportements chez les calopsittes dans un cadre reproductif.

Nous n'avons pas exploré les hypothèses qui permettraient d'expliquer pourquoi les femelles calopsittes choisiraient les mâles les plus capables de produire des sons, de chanter et de tambouriner. De plus, ces résultats sont à replacer dans le cadre de la captivité des oiseaux étudiés : les occupations sont en effet moindres que dans la nature, et il est possible que les calopsittes aient en partie montré ces comportements afin de pallier leur ennui. Cependant, il est intéressant de noter que chez une autre espèce de cacatuidae étudiée dans la nature, les cacatoès noirs, les mâles fabriquent des baguettes de bois avec lesquels ils rythment, et que dans la majorité des cas les femelles semblent en être l'auditoire (Heinsohn et al., 2017). Parce que ces rythmes diffèrent en fonction des individus, les auteurs ont suggéré qu'ils transmettaient des informations sur celui qui les produisait (Heinsohn et al., 2017) : chez les humains, il a été montré que le tempo spontané ralentissait avec l'âge (Drake et al., 2000). Comme chez les cacatoès, les tambourinages que nous avons étudiés chez les perruches calopsittes et les corbeaux à gros becs font état d'une certaine régularité. Il est cependant intéressant de rappeler que chez les corbeaux à gros becs, ce sont des femelles qui ont montré ces tambourinages, mais leur trop petit nombre (deux) ne permet pas de conclure quant à une éventuelle influence du sexe sur ce comportement.

Comme cela a déjà été détaillé dans l'introduction, chez plusieurs espèces animales et notamment de nombreuses espèces d'oiseaux, les chants et les rythmes apparaissent majoritairement chez les mâles pendant la saison des parades (voir par exemple Searcy & Andersson, 1986). Miller (2000) remarque de plus que la production de musique et de danse était sans doute particulièrement coûteuse pour nos ancêtres (risque d'attirer les prédateurs à cause du bruit, mouvements requérant beaucoup d'énergie, longue pratique nécessaire…), ce qui est peu adapté en matière de survie. Cependant chez l'être humain, il y a peu d'éléments permettant d'appuyer l'idée selon laquelle la musique servirait dans le cadre de la sélection sexuelle. Nous savons néanmoins que les chants et les danses des oiseaux par exemple partagent un certain nombre de points communs avec ceux des humains (Verpooten & Nelissen, 2009) : l'être humain aurait pu reprendre chez d'autres animaux des comportements qui, pour les espèces imitées, s'inscrivent dans le cadre de la sélection sexuelle, posant ainsi les bases de certaines pratiques artistiques. D'autres éléments seraient nécessaires pour conclure sur l'émergence de la musique dans un cadre de sélection sexuelle chez l'être humain.

2. Le jeu comme précurseur de la musique

Le jeu et l'art (Grosse, 1914), et plus spécifiquement la musique, partagent plusieurs points communs (Cross & Morley, 2008). Partant de ce constat, certains auteurs ont suggéré qu'une forme de jeu serait peut-être à l'origine de la musique : pour Groos (1919) par exemple, les fêtes primitives, avec leurs musiques et leurs danses, tenaient beaucoup du jeu.

Nos données révèlent que les calopsittes élégantes montrent des comportements de jeu induisant la production volontaire de sons, c'est-à-dire qu'elles sont capables de manipuler des objets, et pour quelques-unes d'entre elles d'utiliser un outil dans le but de produire un son, selon les critères qui définissent le jeu. Chez les oiseaux les plus jeunes, les manipulations sont plus fréquentes et plus souvent sonores que chez les adultes. Le choix des oiseaux de manipuler davantage avec bruit que sans est intéressant, et ce particulièrement dans le cadre de l'étude de la musicalité chez une espèce non-humaine. Ces résultats peuvent donc être rapprochés de l'idée selon laquelle le jeu, en tant qu'exploration sonore de l'environnement, aurait permis le développement de la musique.

Chez les oiseaux chanteurs, il a d'ailleurs été suggéré que la pratique du chant pouvait être assimilée à une forme de jeu (Riters et al., 2019).

Chez les enfants, musique et jeu sont liés sur le plan ontogénétique (Papousek, 1996). Les comportements musicaux précoces pouvent être décrits comme des formes de jeu : les activités musicales spontanées (chant, exploration sonore et danse) font souvent partie des jeux, car les enfants passent facilement d'un mode d'expression à un autre (Niland, 2009). Suliteanu (1979) décrit même ce qu'il qualifie de « chansons pour jouer » (« play songs » en anglais), des chansons qui ont pour but d'amuser l'enfant et impliquent différents mouvements corporels de base (monter ses bras, jouer avec les doigts ou la paume, se faire chatouiller, bouger ses mains et ses pieds). La musique joue donc un rôle central dans le développement du jeu à travers les cultures et le temps (Littleton, 1998). Plus encore, pour certains auteurs, l'art de haut niveau chez l'adulte (Groos, 1919) puiserait ses racines dans les comportements d'expérience et d'imitation induits par le jeu : le jeu combinatoire serait un composant vital du processus créatif (Stevens, 2014).

Cependant, on pourrait également se demander si, en montrant ces comportements de production sonore, les oiseaux ne se contentent pas d'enrichir leur environnement auditif. Les résultats obtenus en matière de production sonore, associés aux autres données récoltées au cours de cette thèse, nous permettent de constater qu'au vu des critères que remplissent les oiseaux, leur sensibilité dépasse la notion d'enrichissement sonore et s'inscrit davantage dans le cadre d'une certaine musicalité. Cependant notre étude portant sur la production sonore ne suffit sans doute pas pour y répondre. En effet, seuls cinq oiseaux (et plus particulièrement un, Seth) ont montré un comportement d'utilisation d'outil dans le but volontaire de produire un son. Le constat seul de cette production ne nous permet pas de trancher entre enrichissement sonore et musicalité. Dans ce cadre, une analyse plus poussée des sonorités produites par les oiseaux pourrait nous en apprendre davantage (par exemple y a-t-il une régularité temporelle dans l'action de poser le grelot sur le xylophone, qui pourrait ressembler à une pulsation?). Par ailleurs, le concept d'enrichissement sonore et celui de musicalité ne sont pas nécessairement incompatibles : comme nous l'avons évoqué plus haut, la musique pourrait être issue d'une exploration sonore de l'environnement qui aurait donné lieu, par la suite, à des sonorités plus structurées : la musique. La capacité à enrichir son environnement d'une façon sonore pourrait donc être un pré-requis indispensable à une certaine sensibilité musicale.

3. Renforcement des liens sociaux, apprentissage vocal et musicalité

a. La musique comme renforçateur des liens sociaux

Suivant l'idée selon laquelle « la musique adoucit les mœurs », chez l'être humain, musicalité et empathie pourraient entre autres avoir évolué biologiquement et culturellement pour renforcer les liens sociaux permettant la formation de sociétés (Freeman, 1998) : la musique aurait donc évolué pour améliorer la coopération et la coordination au sein d'un groupe.

Notre étude portant sur les influences de la musique sur le comportement a montré que l'écoute de musique favorisait les interactions sociales positives : moins de comportements agonistiques et plus de proximité spatiale entre les calopsittes élégantes, et plus d'échanges de regards, de sourires et d'interactions verbales chez les enfants de maternelle. Ces résultats sont cohérents avec l'hypothèse de la musique comme renforçateur des liens sociaux. Ils soutiennent également l'idée selon laquelle la musique ne serait pas uniquement une création culturelle, mais aussi une adaptation évolutive : puisqu'elle influence positivement les interactions sociales, elle aurait pu, en améliorant la cohésion du groupe, renforcer la survie et le succès reproducteur des individus la pratiquant. Cela expliquerait également sa présence au sein de toutes les cultures humaines.

D'autres études ont montré une influence positive de la diffusion de musique sur les comportements sociaux, et ce aussi bien chez l'être humain (Guétin et al., 2009 ; Choi et al., 2008 ; Geravand & Nuorifard, 2014) que chez des espèces non-humaines telles que les chimpanzés de laboratoire (Videan et al., 2007) et les gorilles en zoos (Wells et al., 2006). Chez l'être humain, certains auteurs ont aussi posé l'hypothèse que la capacité à se synchroniser serait en lien avec la socialité : nous aurions une tendance comportementale à bouger en musique parce que cette aptitude permet la synchronie interpersonnelle, ce qui induit un certain nombre de conséquences prosociales conférant des avantages aux individus vivant dans les groupes qui pratiquent de la musique (Bowling et al., 2013 ; Cirelli, 2018 ; Marsh et al., 2013; McNeill, 1997; Peckel et al., 2014). Comme les êtres humains, les psittaciformes sont capables de danser en rythme (Schachner et al., 2009). Parce qu'ils sont grégaires, il a été supposé que cette capacité était en lien avec certaines actions sociales (Fitch, 2009) : chez le cacatoès Snowball, par exemple, danser semble être un comportement

social utilisé afin d'interagir avec les humains qui s'occupent de lui (autrement dit son groupe de substitution) (Jao Keehn et al., 2019).

Par ailleurs, cette hypothèse nécessite d'être approfondie, et ce d'autant plus que tous les types de musique n'induisent pas forcément les mêmes effets en fonction des individus et des espèces auxquels ils appartiennent : il a par exemple été montré que la musique classique augmentait les comportements de peur chez les poules (Campo et al., 2005) et que les gorilles montraient plus de stéréotypies à la diffusion de rock et de musique classique (Robbins & Margulis 2014). Chez l'être humain, une étude a suggéré que l'influence de la musique différait en fonction des préférences musicales individuelles (Sharman & Dingle, 2015) : il serait donc intéressant d'étudier par exemple l'influence de la musique sur les comportements sociaux au sein d'un groupe dont les individus auraient les mêmes préférences musicales.

Les effets de la production musicale sur le renforcement des liens au sein d'un groupe social restent également à étudier. Dans ce cadre, cette notion de groupe social pourrait être précisée. Nous nous sommes penchés ici sur l'ensemble des calopsittes du laboratoire en considérant que, vivant dans la même volière, elles constituaient un groupe social ; mais des sous-groupes peuvent également s'être formés (les oiseaux de la même famille tendent, par exemple, à passer beaucoup de temps ensemble). Or la coordination d'un ensemble de personnes peut également engendrer une certaine compétition vis à vis de ceux qui n'appartiennent pas à la même communauté : les chants des soldats par exemple sont utilisés pour renforcer la solidarité au sein d'un groupe (Cleveland, 1985), et donc d'une certaine manière pour vaincre plus facilement l'ennemi. Chez certains oiseaux (Sonnenschein & Reyer, 1983) et plus spécifiquement des perroquets tels que les amazones à nuque d'or (Dahlin & Whright, 2012), il a également été montré que les duos vocaux pouvaient renforcer les liens au sein d'un couple en permettant une défense conjointe du territoire. Il serait donc pertinent d'étudier le renforcement des liens sociaux que la musique induirait au sein de chaque groupe, mais également la compétition inter-groupes qui pourrait en résulter.

b. L'apprentissage vocal, un facilitateur de la musicalité

L'apprentissage vocal est un processus par lequel la production vocale peut être modifiée en fonction des informations auditives externes (Schusterman, 2008). Certains

auteurs le lient à une certaine sensibilité musicale : un stimulus musical serait essentiellement renforçateur chez les espèces qui apprennent des stimulations auditives complexes pendant leur ontogenèse (Watanabe et al., 2009), et ce trait serait également un pré-requis à la capacité à suivre un rythme (Patel et al., 2009).

Notre étude portant sur l'influence de la musique a montré que les calopsittes élégantes avaient moins de comportements de maintenance (ils bougent moins et ont moins tendance à s'envoler), qu'ils déchiquetaient moins les jouets, étaient plus immobiles et plus détendus quand ils entendaient de la musique comparé au silence. Ces résultats suggèrent que les oiseaux accordent une attention particulière à la musique et qu'en conséquence, ils stoppent leurs activités habituelles. Notre étude menée sur les préférences musicales a également montré que trois individus avaient des préférences musicales individuelles, deux femelles pour le rock et un mâle pour la musique calme. Enfin, la recherche portant sur la production sonore et rythmique a montré des jeux d'objets sonores chez les calopsittes, ce qui permet de supposer que manipuler des objets bruyants leur était plaisant. Nous avons également montré que certaines calopsittes et corbeaux à gros bec tambourinaient des séquences de coups réguliers pendant plus ou moins longtemps et sur différents supports, et que ces tambourinages différaient en fonction des espèces. Les individus de ces deux espèces étant capables d'apprentissage vocal, nos résultats vont donc dans le sens d'un lien entre ce trait et une certaine sensibilité à la musique.

Il est cependant important de noter que nous n'avons étudié, au cours de ce travail de thèse, aucune espèce qui serait incapable d'apprentissage vocal. De plus, les résultats chez les corbeaux à gros bec sont beaucoup plus mitigés en ce qui concerne la présence d'une éventuelle musicalité (pas d'influence de la musique sur les comportements ni de préférences musicales mises en évidence). Dans le cadre de cette hypothèse, nos données sont donc à interpréter avec précautions. Ce d'autant plus que si, initialement, il a été posé une frontière claire entre les espèces capables d'apprentissage vocal et celles n'en étant pas capables, les éléments scientifiques actuels ne vont pas dans le sens d'une distinction aussi nette. Arriaga & Jarvis (2013) ont donc proposé « l'hypothèse du continuum », selon laquelle la capacité d'apprentissage vocal serait distribuée le long d'un large spectre de traits comportementaux et neuronaux, partant des espèces totalement incapables d'apprentissage vocal jusqu'à celles qui en auraient une capacité complexe, en passant par celles chez lesquelles cette aptitude serait limitée. Or les données disponibles vont, elles

aussi, plutôt dans le sens d'une sensibilité musicale présente à différents degrés en fonction des espèces, et non d'une capacité qui serait soit incontestable soit totalement inexistante. Concernant les primates non-humains par exemple, les résultats des études, bien que contrastés, ont mis en évidence un effet renforçateur de la musique chez des gorilles en zoo (Wells et al., 2006), une préférence pour la musique indienne chez des chimpanzés (Mingle et al,. 2014), la synchronisation avec une pulsation chez les macaques (*Macaca mulatta*) (Zarco et al., 2009) et un bébé chimpanzé (Hattori et al., 2013) et chez un autre chimpanzé, la capacité à produire de façon spontanée un tempo bi-manuel partageant certaines caractéristiques du tambourinage humain (Dufour et al., 2015). D'autres études portant sur des espèces peu ou pas capables d'apprentissage vocal ont montré une capacité à discriminer des mesures chez les pigeons (Hangmann & Cook, 2010), un effet renforçateur de la musique chez des chiens captifs (Kogan et al., 2012; Wells et al., 2002; Boone & Quelch 2003), et des préférences musicales chez les octodons (*Octodon degus*) (Watanabe et al., 2018), et les souris si elles y sont exposées entre leur quinzième et leur vingt-cinquième jour de vie (Yang et al., 2012). Au vu de ces résultats, l'hypothèse selon laquelle la sensibilité à la musique et au rythme existerait essentiellement chez les espèces capables d'apprentissage vocal a été modérée. Merchant & Honing (2014) ont par exemple proposé « l'hypothèse graduelle audio-motrice », selon laquelle la capacité à suivre un rythme se serait développée de façon graduelle chez les primates et culminerait au sein de l'espèce humaine ; ce postulat se base entre autres sur le constat que l'intégration d'informations sensorimotrices pendant la perception ou l'exécution d'intervalles simples à travers, d'une part, les ganglions moteurs corticaux de la base du circuit thalamo-cortical et d'autre part, les autres aires du cerveau, est similaire chez les humains et les primates (Merchant & Honing, 2014). Mais la suggestion selon laquelle le degré d'apprentissage vocal serait corrélé avec le degré de musicalité est toutefois elle aussi à prendre avec précaution : en matière d'imitation vocale, l'être humain est loin d'être le meilleur candidat puisqu'il se fait surpasser par les cétacés, qui sont, eux, moins performants que certains oiseaux (Mercado et al., 2014) ; d'autres études sur l'apprentissage vocal seraient donc nécessaires, afin notamment d'en préciser la définition.

c. Une relation entre apprentissage vocal et renforcement des liens sociaux ?

Nous avons précédemment discuté de la relation qu'il pouvait y avoir entre d'une part, la musicalité et le renforcement des liens sociaux et d'autre part, la musicalité et l'apprentissage vocal. Certains auteurs se sont également penchés sur l'existence éventuelle d'un lien entre apprentissage vocal et renforcement des groupes : l'apprentissage vocal et la capacité à imiter des sons seraient en effet utiles au sein des systèmes sociaux complexes (Janik, 2009) et permettraient dans certains cas la cohésion du groupe (Janik & Slater, 1997). Wilkinson (2003) encourage à faire des comparaisons directes entre les différents degrés de complexité vocale des espèces formant des liens sociaux sur le long terme.

Chez l'être humain, nous savons qu'un lien s'établit dès la douzième semaine de gestation entre le développement vocal et le développement moteur (de Vries et al., 1985) et que cette coordination voco-motrice permet chez les bébés de développer ce qui deviendra les gestes co-verbaux (les gestes accompagnant la parole) chez les adultes (Iverson, 2010). Pour Aiello & Dunbar (1993) la communication vocale serait un mécanisme efficace servant à renforcer les liens sociaux : il y a donc un rapport entre l'apprentissage vocal et la sociabilité. C'est également le cas chez d'autres espèces : l'apprentissage vocal pourrait avoir évolué pour permettre les négociations sociales et la reconnaissance entre mères et petits chez les odontocètes (Janik, 2014) et il se retrouve chez les chauves-souris dans la communication qui s'exprime lors des activités sociales (Prat et al., 2015). Chez les psittaciformes, l'apprentissage vocal a aussi souvent été lié aux groupes sociaux : la taille du répertoire vocal serait directement liée à l'organisation sociale d'une espèce donnée (Martella & Bucher, 1990) et la concordance vocale (le fait d'imiter divers cris produits par d'autres que soi) permet une forme de négociation entre les individus de deux groupes différents (Balsby & Bradbury, 2009) ; chez les perruches ondulées, l'apprentissage vocal joue même un rôle dans la formation des couples, puisqu'une femelle choisira davantage un mâle faisant concorder ses cris avec les siens (Moravec et al., 2005).

Musicalité, apprentissage vocal et cohésion sociale pourraient donc être différents traits liés sur le plan évolutif ; par conséquent, il serait intéressant d'étudier ces trois éléments ensemble afin d'en apprendre davantage sur une éventuelle relation entre eux.

IV. Implications pour le bien-être et autres éléments mis en évidence

1.Des implications concrètes pour le bien-être animal

Ce travail de thèse pourrait également trouver certaines applications dans le domaine du bien-être et de l'enrichissement de l'environnement chez les animaux captifs.

Notre étude s'intéressant aux influences de la musique chez les calopsittes élégantes a montré que les oiseaux sont physiquement plus proches les uns des autres et qu'ils ont moins de comportements agonistiques quand ils écoutent de la musique que lorsqu'ils n'en écoutent pas. Diffuser de la musique aux animaux qui semblent y être positivement sensibles pourrait donc améliorer leur bien-être, et ce particulièrement chez certains animaux captifs tels que les animaux d'élevages ou de zoos, qui ont tendance à se montrer plus agressifs les uns envers les autres que les animaux libres, en raison de l'espace restreint qu'ils doivent partager, de la composition artificielle des groupes, etc..

Cette même étude a montré que les oiseaux étaient spécialement proches les uns des autres quand ils écoutaient de la musique consonante. Combinés à une autre recherche qui a mis en évidence des préférences musicales individuelles chez certaines calopsittes, ces résultats nous montrent que le stimulus musical choisi revêt une importance particulière. Il serait par ailleurs intéressant de reproduire ces même tests après un délai de quelques mois, voire quelques années, afin d'en savoir plus sur la stabilité des choix des individus. En matière de bien-être animal, les tests de choix se retrouvent en effet souvent, car ils permettent de suggérer ce que l'animal souhaite pour son plaisir, son confort ou sa satisfaction (McPhee & Carlstead, 2010). Afin que l'écoute de musique soit véritablement bénéfique aux animaux captifs, il est donc important d'adapter ce qui est diffusé à chaque individu en fonction de ses préférences musicales du moment ou, lorsque ce n'est pas possible, du plus grand nombre. Notamment, et bien que nos données aient porté sur trop peu d'individus pour en tirer des conclusions, cette étude est la première à s'intéresser à une éventuelle relation entre les choix musicaux et la personnalité chez une espèce non-humaine. Nous espérons qu'elle inspirera d'autres chercheurs. De plus, la possibilité qu'ont eue les calopsittes de notre étude grâce à l'écran, non seulement de choisir la musique mais

également de la déclencher eux-mêmes lorsqu'ils le souhaitaient, mériterait d'être proposée à d'autres espèces.

Enfin, une troisième recherche a montré que les calopsittes interagissaient de façon répétitive avec les objets sonores que nous leur avions fournis, et que ces interactions pouvaient être qualifiées de jeu. Il est donc probable que manipuler ces objets ait été une activité plaisante, et que cette mise à disposition ait constitué un enrichissement de leur environnement, ce d'autant plus que les comportements de jeu ont déjà été utilisés comme indicateurs d'un état émotionnel positif (Jensen et Kyhn, 2000). Proposer des objets sonores avec lesquels des individus captifs peuvent jouer semble donc être une autre source d'enrichissement et de bien-être, au moins chez certaines espèces d'oiseaux.

Ces données peuvent aider à améliorer le bien-être d'animaux captifs, mais également ouvrir la voie à d'autres recherches. McPhee et Carlstead (2010) supposent qu'en condition de captivité, le manque quantitatif et de diversité de stimuli engendre souvent un environnement sensoriel trop pauvre qui causerait un mal-être. Leur proposer, entre autres, un milieu auditivement complexe réduirait les comportements négatifs (McPhee & Carlstead, 2010). C'est la raison pour laquelle il est important d'étudier, comme nous l'avons fait au cours de ce travail de thèse, différents aspects de la musique et de la musicalité, afin d'adapter au mieux l'enrichissement sonore aux individus concernés.

Dans ce cadre, notre modèle animal était particulièrement pertinent : les perroquets cohabitent avec les êtres humains comme animaux de compagnie depuis longtemps, et ce dans de nombreuses cultures (Auersperg & von Bayern, 2019). À l'heure actuelle, des millions d'entre eux vivent dans un foyer humain. Engebretson (2006) suggère d'ailleurs que les nombreux comportements anormaux relevés chez les perroquets en captivité pourraient être liés à leurs hautes capacités cognitives.

Concernant les corbeaux à gros bec, ces implications pour l'enrichissement et le bien-être restent cependant plus réservées : notre étude portant sur l'influence et les préférences musicales n'a en effet montré aucun effet positif de la musique chez ces oiseaux. Il se trouve que le contexte scientifique dans lequel a été effectuée cette recherche au Japon est très différent des conditions dans lesquelles nous avons étudié les calopsittes en France : les calopsittes étaient nées en captivité, apprivoisées et vivaient ensemble dans une grande volière où se déroulaient tous les tests, alors que les corbeaux étaient sauvages et avaient

été capturés dans la nature, ils étaient hébergés dans de petites cages individuelles (dans la même pièce) et devaient être attrapés (ce qui semblait être source d'un grand stress au vu de la manière dont ils se débattaient) avant le test pour être placés seuls dans une volière extérieure, dont nous ne pouvions pas contrôler l'environnement sonore. Enfin, les protocoles mis en place entre les deux espèces étaient différents. Les résultats de cette étude concernant les corbeaux sont donc à prendre avec précautions.

2. Des différences individuelles et pas de préférence universelle pour la consonance

Au travers de ces différentes études, nous avons pu constater la diversité comportementale présente au sein de notre échantillon. Chez les calopsittes élégantes, lors de notre étude sur les préférences musicales, sept individus ont interagi avec le dispositif : Gaïa, Nephtys, Éole, Seth, Odin, Hermès et Isis. Seuls trois d'entre eux ont montré des préférences musicales : Gaïa, Nephtys et Éole, probablement parce qu'ils étaient plus motivés que les autres, qui, Seth mis à part, n'ont que très peu voire pas du tout interagi avec le dispositif. Les tambourinages observés chez les calopsittes montrent également des différences individuelles au niveau de la durée de l'intervalle entre les coups frappés, mais les différences ne sont pas significatives. Nos observations ont malheureusement été limitées : il n'est pas possible de laisser une caméra sans surveillance dans la volière, car en plus de modifier les réglages les oiseaux grugent les fils et arrachent les petites pièces ; il est donc indispensable, soit que quelqu'un soit présent, soit de protéger l'intégralité du matériel, ce qui entrave la qualité de la vidéo. L'analyse de ces comportements de tambourinage mériterait donc d'être approfondie au niveau individuel. Notre étude portant sur la production sonore a montré que quatre individus ont posé ou lâché un grelot sur le xylophone : Seth, Isis, Odin et Loki, et parmi eux seul Seth a répété ce comportement à de nombreuses reprises et visiblement dans le but de produire un son. Par ailleurs, les tests de personnalité que nous avons fait passer aux calopsittes ont montré une grande diversité entre les oiseaux de notre échantillon. Il est donc important de rappeler que nos résultats sont extrêmement dépendants des individus, et que ces données ne sont représentatives que de certains d'entre eux. L'étude portant sur les préférences musicales chez les paddas de Java (Watanabe & Nemoto, 1998) révèle d'ailleurs que sur quatre individus, seuls deux ont montré des préférences musicales. Cette diversité illustre sans doute bien les différences

subjectives qui existent également au sein de l'espèce humaine en ce qui concerne l'influence, l'appréciation et la production de musique.

Un autre résultat intéressant de ce travail de thèse concerne l'absence de préférence des calopsittes pour la consonance par rapport à la dissonance, contrairement à ce que nous avions postulé. Les résultats de notre recherche suggèrent que les calopsittes discriminent la consonance de la dissonance : leurs comportements sont différents à la diffusion de musique consonante par rapport à la diffusion de musique dissonante (les oiseaux montrent moins de chants, de toilettages auto ou mutuels, de sollicitations de toilettage et de déchiquetage de jouets à la diffusion de musique consonante qu'à la diffusion de musique dissonante). Cette capacité à distinguer la consonance de la dissonance apparaît très tôt au sein de l'espèce humaine, puisque des bébés de deux jours en sont déjà capables (Masataka, 2006) ; notre étude portant sur les enfants montre d'ailleurs également des différences comportementales entre l'écoute de musique consonante et dissonante. Mais elle existe aussi chez plusieurs espèces non-humaines, qu'elles soient capables d'apprentissage vocal comme les paddas de Java (Watanabe & Nemoto, 1998) ou non, comme les macaques japonais (Izumi, 2000) ou les rats (Crespo-Bojorque & Toro, 2015). En 2015, Bowling & Purves suggèrent qu'un sens biologique de la consonance se développerait chez toute espèce dont la communication vocale générerait des harmoniques ; or les cris de contact des perroquets comportent plusieurs séries d'harmoniques (Balsby et al., 2012).

Cependant notre étude portant sur les préférences musicales chez les calopsittes n'a mis en évidence, chez les deux individus ayant interagi avec le dispositif proposé, aucune préférence pour la consonance ni la dissonance (alors que Nephtys, l'une des oiselles, avait montré au cours d'un test précédent une préférence pour le rock par rapport à la musique calme). Ces données vont à l'encontre de l'idée d'une préférence universelle pour la consonance. Il se trouve que les résultats de certaines recherches récentes remettent également cette vue en perspective, et laissent à penser que l'expérience jouerait un rôle prépondérant dans la préférence pour la consonance, comme cela a été constaté chez des enfants de six mois (Plantinga & Trehub, 2014) et suggéré chez la tribu amazonienne des Chimane (McDermott et al., 2016), qui discriminent consonance et dissonance sans montrer de préférences. Or l'étude portant sur les préférences musicales s'est déroulée après celle portant sur les influences de la musique, et utilisait les même stimuli musicaux que cette

dernière ; les calopsittes avaient donc déjà été exposées à ces deux types de musique, et ont eu le temps de s'y habituer. Ces résultats tendent donc à montrer qu'en matière de préférences musicales, il n'y a pas d'universalité.

3. L'utilisation d'outil

Enfin, notre étude portant sur l'expression sonore chez les calopsittes élégantes a mis en évidence, et ce pour la toute première fois chez cette espèce, l'utilisation d'un outil dans le but de produire un son. Seth a en effet, à de nombreuses reprises (198 fois), combiné un grelot avec un xylophone afin de produire délibérément un son lors d'un jeu d'objet non récompensé. Ce comportement était inattendu, dans la mesure où aucun expérimentateur ne lui a montré l'exemple ni ne l'a encouragé dans cette direction.

Il a été suggéré que les perroquets, qui ont d'une part une patte zygodactyle adroite et d'autre part un bec en forme de crochet extrêmement puissant permettant tous deux des manipulations précises, étaient suffisamment équipés pour accéder et traiter presque toute source de nourriture sans avoir besoin d'outils (Striedter, 2013). Plusieurs formes d'utilisation d'outils ont cependant déjà été observées chez les psittaciformes, surtout en captivité : l'exemple le plus classique est sans doute celui qui consiste à utiliser un objet pour se gratter (pour une revue, voir Shumaker et al., 2011). Le reste des données concerne essentiellement de l'utilisation d'outil à but nutritif : le grand vasa (*Coracopsis vasa*) utilise des cailloux et des noyaux de dattes pour gratter ou casser des coquillages avant d'en ingérer la poudre et les morceaux obtenus (Lambert et al., 2015), les perruches à tête d'or (*Cyanoramphus auriceps*) (Funk et al., 2002) et les nestors kéa (Gajdon et al., 2011) peuvent utiliser un bâton pour obtenir une récompense et certains cacatoès fabriquent des outils pour récupérer de la nourriture inaccessible autrement (Auersperg et al., 2012). Le fait que Seth utilise cet outil dans un but non alimentaire mérite donc d'être relevé, et rappelle davantage les comportements des cacatoès noirs qui rythment sur des troncs creux avec des baguettes qu'ils fabriquent (Wood, 1984). Ce comportement pourrait également être un cas d'innovation d'outil. L'innovation d'outil est définie par Beck et al. (2011) comme le fait de créer un outil sans en avoir vu de fonctionnel auparavant, simplement via l'exposition aux potentialités d'une situation donnée. Elle a été documentée à plusieurs reprises chez les

nestors kéa, qui sont capables d'utiliser des bâtons comme outils de façon spontanée (Auersperg et al., 2011 ; Lambert et al., 2017). Seth n'ayant jamais observé une telle combinaison entre un grelot et un xylophone dans le passé, il a innové et ainsi créé un outil dans le but de produire du son.

Quatre autres oiseaux ont montré ce comportement, bien que dans une moindre mesure. Le fait qu'ils aient posé ou lâché le grelot de la même manière mais après que Seth a commencé peut suggérer une forme d'apprentissage social. La transmission sociale d'outils a, elle aussi, déjà été observée chez deux espèces de psittaciformes : les cacatoès de Goffin (Auersperg et al., 2014b) et les nestors kéa (Gajdon et al., 2011) sont capables, lorsqu'ils sont exposés à un oiseau fabricant ou utilisant un outil, de reproduire ses actions. Parmi les quatre individus qui ont montré le même comportement que Seth, deux sont de la même famille que lui : Bahloo est son frère et Isis sa fille. Certaines observations soulignent le fait que les oiseaux tendent à imiter davantage les comportements d'individus familiers, par exemple en ce qui concerne la construction du nid (Guillette et al., 2016). Par ailleurs, les perroquets imitent plus les oiseaux avec lesquels ils ont des affinités : notamment, les mâles des perruches ondulées reproduisent le cri de contact de leur partenaire sexuelle (Hile et al., 2000).

V. Conclusion générale

1. Conclusion

Ce travail de thèse nous a permis de constater que les calopsittes élégantes remplissaient au moins deux critères relevant de la musique : elles produisent des sons de façon intentionnelle (1) et tambourinent selon une pulsation régulière (2), ce dernier critère étant également partagé avec les corbeaux à gros becs, et quatre relevant de la musicalité : elles sont influencées par la musique (1), peuvent discriminer deux types de musique différents (2) et se montrent créatives (3) sans récompense par l'intermédiaire de jeux d'objet, ce qui suppose qu'elles y prennent plaisir (4). D'autres critères ont été plus délicats à

explorer. Nous n'avons, par exemple, pas pu montrer que les oiseaux préféraient la musique à tout autre type de bruit pour des raisons de temps et de protocole, ni que la musique en elle-même pouvait être une récompense, en raison de défaillances matérielles.

Ce projet de recherche a également permis d'apporter des informations concernant différentes hypothèses évolutives qui éclairent l'apparition de la musique au sein des sociétés humaines. Nos résultats vont notamment dans le sens d'un lien entre musicalité et sélection sexuelle. Ils sont également compatibles avec l'idée qu'un jeu sonore aurait pu être un facteur permettant l'apparition de la musique. De plus, ils montrent une possible relation entre apprentissage vocal, liens sociaux et musicalité. Ces données renforcent donc l'idée d'une convergence évolutive entre les êtres humains et certaines espèces d'oiseaux en ce qui concerne deux traits : l'apprentissage vocal et la musicalité.

Ces résultats peuvent avoir des applications concrètes en matière de bien-être et d'enrichissement animal : ils nous ont en effet permis de savoir que la musique pouvait avoir une influence positive sur les comportements sociaux, qu'il était important d'adapter les stimuli aux individus ciblés et que la mise à disposition d'objets sonores permettait aux animaux des manipulations et des comportements de jeu.

Enfin, nous avons mis en évidence d'autres éléments, qui ne sont pas directement liés à la musique ou à la musicalité mais restent cependant intéressants, notamment dans le cadre de la cognition aviaire. En plus des différences individuelles importantes observées au sein de notre échantillon, au moins une calopsitte s'est montrée capable d'innovation d'outil et d'utiliser cet outil à de nombreuses reprises dans le but de produire un son, un comportement qui a été reproduit par quatre autres oiseaux.

2. Ouverture sur de futures recherches

La notion de musique et de musicalité chez l'animal non-humain est relativement récente, et de nombreux aspects de cette thématique restent à explorer.

Tout d'abord, il me semble important de préciser que les calopsittes qui ont fait l'objet de cette thèse vivent dans un milieu très anthropisé : elles sont nées, ont grandi et vécu au

contact d'êtres humains. Par conséquent, on ne peut écarter l'hypothèse que leurs réactions face à des stimuli humains (comme c'est le cas de la musique), soient différentes de celle d'oiseaux sauvages, du fait de l'environnement anthropisé dans lequel elles évoluent. Bien que nous ayons fait attention à ce qu'elles n'entendent pas de musique avant le début de cette thèse, en tant qu'animaux de laboratoire, elles ont l'habitude d'être confrontées à différents dispositifs expérimentaux, et des stimuli sonores leur avaient été préalablement diffusés pour les besoins d'autres recherches. Il n'est donc pas impossible que la diffusion de musique les ait influencées différemment qu'elle ne l'aurait fait pour des animaux dans la nature.

Il me semble également particulièrement intéressant de se demander ce qui, pour l'oiseau, relève du domaine de la musicalité ou non. Nous nous sommes ici posés la question de savoir si des animaux non-humains pouvaient avoir une certaine conception de la musique, mais il serait aussi intéressant de se demander si cette conception serait la même que la nôtre. von Uexküll (1965, p. 29) explique que nous avons tendance à négliger le fait que les autres espèces ne vivent pas forcément dans le même temps et le même espace que nous : « Cette illusion repose sur la croyance en un monde unique dans lequel s'emboîteraient tous les êtres vivants ». Cependant, un même stimulus n'a pas forcément la même signification pour deux individus appartenant à deux espèces différentes (von Uexküll, 1965).

Nous nous sommes beaucoup intéressés à l'effet que pouvait avoir une musique humaine sur deux espèces qui ne le sont pas : lors de nos recherches portant sur l'influence de la musique et les préférences musicales, nous avons diffusé des morceaux de musique humaine, autrement dit des stimuli artificiels, qui ne sont pas nécessairement les seuls à être pertinents dans le cadre d'une recherche de ce style. S'il était, à mon sens, intéressant de tester la réaction des oiseaux à l'écoute de musique humaine, et ce d'autant plus au vu des points communs partagés par cette même musique et le chant des oiseaux, d'autre stimuli auraient également pu nous en apprendre davantage sur la question de la musicalité au sein du règne animal. Certaines espèces pourraient notamment avoir une musicalité remplissant certains critères de la nôtre mais qui leur serait propre et à laquelle ils seraient tout aussi sensibles, voire plus, qu'à notre musique.

Nous avons vu que les productions sonores des calopsittes élégantes remplissaient plusieurs critères de la musique (intentionnalité et régularité de la pulsation) et de la musicalité (influence positive de la musique, discrimination, plaisir et créativité). Les corbeaux à gros becs ont également produit des tambourinages réguliers. Il serait donc intéressant d'étudier la réaction des oiseaux à ces productions sonores et rythmiques issues de leur espèce. Dans ce cadre, diverses mesures physiologiques et comportementales pourraient être prises en compte pour nous permettre d'explorer leur sensibilité à ces productions issues de leur propre espèce : influencent-t-elles leurs comportements et leurs émotions, et si oui, comment ? Y sont-ils particulièrement attentifs ? Les préfèrent-ils à la musique humaine ? La réponse à ces questions pourrait permettre d'ouvrir davantage notre conception de la musique à l'animalité.

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A la mémoire de

Wala, Sîtâ, Skadi

Merlin et Gaïa

Annexes

Variation des mouvements de la crête en fonction du contexte émotionnel chez les calopsittes élégantes

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Contexte de l'étude

Cette étude part de l'observation suivante : la crête des calopsittes élégantes est très mobile, et sa position semble dépendre du contexte émotionnel et comportemental, mais aussi de la personnalité des oiseaux. Nous avons donc cherché à savoir si les mouvements de la crête pouvaient nous en apprendre davantage sur leurs émotions. Dans le cadre d'une recherche sur l'influence de la musique, de telles données peuvent se révéler particulièrement intéressantes : à la lumière des résultats trouvés, nous pourrions ainsi affiner l'interprétation des comportements que les oiseaux montrent à l'écoute de musique en nous basant sur la position de leur crête.

Cette annexe présente brièvement le cadre de cette étude et quelques résultats préliminaires. Ils ne sont bien sûr pas suffisants pour permettre de conclure de façon tranchée et nécessiteront d'être approfondis. Quelques éléments mis en évidences semblent néanmoins intéressants.

Cadre théorique

On parle de communication quand un individu produit un signal porteur d'information induisant une réponse chez celui qui le reçoit (Ruiz-Rodríguez et al., 2017). La communication est une composante importante des interactions sociales. Parmi les différents signaux transmis d'un individu à l'autre, les états émotionnels peuvent notamment se manifester par le biais de la communication visuelle.

Chez l'être humain, cette communication visuelle peut s'exprimer via les expressions du visage qui serviraient à transmettre nos émotions dans un contexte social ; il existe d'ailleurs une homologie entre les expressions faciales des humains et des primates non humains (pour une revue, voir Schmidt & Cohn, 2001).

Chez les oiseaux, un certain nombre d'études se sont intéressées à la communication par l'intermédiaire de signaux vocaux. Cependant de plus en plus de recherches montrent

l'importance des signaux visuels dans le cadre des échanges sociaux. Les oiseaux peuvent notamment transmettre des informations par l'intermédiaire de mouvements spécifiques de la tête, du corps, des ailes ou de la queue, mouvements qui sont souvent mis en valeur par leurs plumages élaborés et colorés (Kumar, 2010) : certaines altérations motrices peuvent donc informer sur l'état émotionnel d'un individu (Hatfield et al., 1993). Goodwin (1995) a par exemple remarqué que chez les geais, la disposition des plumes (qui peuvent se dresser ou s'aplatir) semblait dépendre principalement de l'humeur de l'oiseau. Chez les psittacidés, les mouvements des plumes dépendent de l'activité dans laquelle l'oiseau est engagé (Bertin et al., 2018).

Un certain nombre d'oiseaux possèdent une crête par le biais de laquelle ils peuvent transmettre des informations (Ruiz-Rodríguez et al., 2017), et ce d'autant plus qu'en général, les plumes de la crête sont plus mobiles que les autres plumes (Andrew, 1961). Chez les bulbuls à ventre rouge (Kumar, 2010) et les huppes (Ruiz-Rodríguez et al., 2017) par exemple, les mouvements de la crête sont des signaux utilisés dans différents contextes de communication. Par ailleurs, une précédente étude portant sur la réaction des calopsittes aux cris de détresse de leurs congénères, effectuée au Laboratoire Ethologie Cognition Développement avec les mêmes oiseaux, a montré que la position des plumes de la crête pouvait donner des informations sur l'attention et l'état émotionnel des oiseaux (Liévin Bazin et al., 2019).

Notre étude souhaite aller plus loin et établir en lien entre le contexte émotionnel, le comportement et la position de la crête, en fonction de la personnalité de chaque individu.

L'étude

Cette étude a pour but de comparer les mouvements de la crête chez treize calopsittes dans différents contextes. Les calopsittes appartiennent à l'ordre des psittaciformes, un ordre dont les oiseaux partagent des capacités cognitives complexes avec les primates. Comme les cacatoès, les calopsittes ont une crête érectile qui bouge fréquemment.

Nous posons les hypothèses suivantes :

(1) La position de la crête varie en fonction de l'état émotionnel de l'oiseau
(2) La position de la crête varie en fonction du comportement de l'oiseau
(3) Face à une même situation, les mouvements de la crête diffèrent en fonction de la personnalité de chaque individu

Protocole

Stimuli

Nous avons observé le comportement des oiseaux quand ils étaient effrayés ou surpris selon deux modalités : visuelle et auditive. Pour chaque modalité, deux types de stimuli étaient utilisés : des stimuli inconnus et des stimuli connus. Chaque configuration était testée dans deux versions différentes (voir le tableau I).

Nous avons également observé le comportement des oiseaux en attente de nourriture, pendant qu'ils se nourrissaient et après (pendant le temps de repos).

- Stimuli alimentaires : chaque oiseau se voyait présenter du fenouil ou des graines (selon sa motivation) pendant au moins 10 secondes avant de pouvoir le manger (nous observions ainsi le comportement d'attente, puis le comportement de nourrissage).
- Les sessions de repos étaient toutes enregistrées dans l'après-midi, entre 14h30 et 16h, un créneau horaire pendant lequel les oiseaux ont tendance à se reposer.

Pour un détail des stimuli, voir le tableau I.

Tableau I : détail des stimuli utilisés

Stimulus type Caractéristiques	Visuel	Auditif
Effrayant familier	Blouse bleue Gants	Cris d'alarme des calopsittes Cris de détresse d'une des calopsittes
Effrayant inconnu	Serpent Rapace	Cris d'alarme de kokako Cri de faucon
Non effrayant familier	Carton Livre	Bruits de volière Voix humaines connues
Non effrayant inconnu	Jeu 1 Jeu 2	Rivière Chant de zostérops à dos gris

Conception expérimentale

Les tests ont été effectués par deux expérimentatrices, familiarisées avec les oiseaux. Chaque session était filmée avec une caméra et durait environ 6 minutes : 3 minutes précédant l'introduction du stimulus (« pré-stimulus ») ont servi de condition contrôle, suivies par 3 autres minutes durant lesquelles le stimulus (« stimulus ») était introduit. La caméra était fixe lors de la phase « pré-stimulus ». Lors de la phase « stimulus », elle était soit fixe soit maniée par l'une des expérimentatrices (essentiellement dans les cas où des stimuli effrayants engendraient chez les oiseaux des comportements d'envols nécessitant d'être suivis).

- Sessions «modalité visuelle » : après 3 minutes, l'objet stimulus, enveloppé dans une blouse blanche, était introduit par une expérimentatrice et dévoilé une fois au milieu de la volière. Les stimuli « effrayants » étaient bougés par l'une des expérimentatrices afin de figurer un prédateur, et les stimuli « surprise » étaient posés sur la paillasse.

- Sessions « modalité auditive » : pendant toute la session, des hauts-parleurs étaient cachés sous l'une des paillasses et activés au bout de 3 minutes pour diffuser le stimulus, « effrayant » ou « surprise ».
- Sessions « alimentaires » : nous attendions 3 minutes avant de nourrir les oiseaux, comme détaillé au-dessus.

Chaque session était séparée de la suivante par au moins une heure. Trois heures minimum séparaient deux sessions « effrayant », afin de laisser aux oiseaux le temps de se remettre. Les moments de la journée (matin et après-midi) étaient contrebalancés pour chaque condition, excepté pour la condition « sieste ». Nos enregistrements nous ont permis d'obtenir un total de 480 minutes (soit 8 heures) d'observation par oiseau.

Codage

Les vidéos ont été codées avec le logiciel Solomon Coder.

À chaque session, nous relevions en continu et par oiseau : la localisation de l'oiseau (perchoir, jouet, porte, barre, cage, corde) ainsi que ses comportements, divisés en 20 catégories rassemblées en 5 groupes : activité globale, interactions sociales, alimentation, indicateurs de sommeil et vocalisations (voir tableau II). Nous avons également relevé les variations de la crête selon trois positions : aplatie, intermédiaire et dressée (voir tableau III et figure 1). La position de la crête était codée sans le son de la vidéo, afin que nous ne soyons pas influencées par l'introduction des stimuli dans la volière : cela nous évitait d'entendre le déclenchement des stimuli auditifs, mais aussi de nous entendre sortir de la pièce pour aller chercher les stimuli visuels ; la caméra étant focalisée sur les oiseaux, le stimulus nous était invisible. Un second codage était effectué pour l'analyse des comportements des oiseaux.

Notre configuration du logiciel comprenant une seule colonne dédiée aux comportements, un seul comportement pouvait être codé pour un temps donné. Les comportements décrits ci-dessous sont donc exclusifs les uns des autres.

Tableau II : comportements relevés

Activité globale	Détendu	Oiseau au repos (plumes un peu ébouriffées, tête rentrée dans le cou)

	Attentif	Oiseau dressé, plumes aplaties
	En mouvement	Oiseau en mouvement (marche,…) pendant au moins 3 secondes consécutives
	Immobile	Oiseau interrompant brusquement son action et s'immobilisant totalement pendant au moins 5 secondes (« freezing »)
	Envol	Oiseau s'envolant
	Toilettage	Oiseau se toilettant, s'étirant ou se grattant
	Grignotage	Oiseau déchiquetant du carton ou mâchouillant un jouet
	Penché	Oiseau se penchant de son perchoir, comme sur le point de s'envoler
Interactions sociales	Toilettage mutuel	Oiseau toilettant un autre oiseau
	Comportement agonistique	Oiseau ouvrant son bec pour menacer / piquer un autre oiseau
	Proximité	Oiseau proche d'un autre oiseau (suffisamment pour pouvoir le toucher)
Alimentation	Attente	Oiseau se penchant de son perchoir, comme pour atteindre la nourriture présentée
	Alimentation	Oiseau mangeant
Indicateurs de repos	Perché sur une patte	Oiseau perché sur une patte, l'autre étant rentrée dans les plumes du ventre
	Yeux fermés	Oiseau fermant les deux yeux
	Tête retournée	Oiseau aux plumes un peu ébouriffées, tournant sa tête à 180 degrés, bec enfoui dans les plumes du dos

Vocalisations	Petit cri	Petit cri d'intensité faible
	Cri de contact	Cri habituellement émis pour établir un contact
	Cri d'alarme	Cri habituellement émis lorsque l'oiseau est confronté à ce qu'il perçoit comme une menace
	Chant	Chant (succession de plusieurs notes)

Tableau III : Positions de la crête

Aplatie	Crête aplatie sur la tête de l'oiseau
Intermédiaire	Crête dans une position intermédiaire (entre aplatie et dressée)
Dressée	Crête dressée, les plumes se distinguant les unes des autres

Figure 1 : exemple des positions de crête chez Skadi

Test de personnalité

Afin de voir s'il est possible d'établir un lien entre les mouvements de la crête et la personnalité de l'oiseau, nous utiliserons dans le cadre de cette recherche les résultats d'un test de personnalité déjà effectué chez les calopsittes pour une autre étude. Ce test est issu d'un article de Cussen and Mench (2014), qui l'ont eux-mêmes adapté d'un test développé par Gosling (1998) pour des hyènes tachetées. Ce test

consiste en 43 traits notés chacun de 0 (complète absence du trait) à 7 (extrême présence du trait).

Analyses statistiques préliminaires

Des analyses statistiques préliminaires ont été effectuées concernant la position de la crête sur les modalités auditives et visuelles avec les stimuli familiers et inconnus. Un modèle linéaire a été réalisé par position de crête et par condition, avec le logiciel R.

Résultats préliminaires et discussion

- En situation “auditive surprise familière”, les oiseaux dressent moins leur crête lors de l’exposition au stimulus (14%) qu’en contrôle (23%) (p= 0.036).
- En situation “visuelle peur familière”, les oiseaux dressent plus leur crête lors de l’exposition au stimulus (39%) qu’en contrôle (17%) (p>0.001).
- En situation “visuelle peur familière”, les oiseaux ont la crête moins aplatie lors de l’exposition au stimulus (15%) qu’en contrôle (26%) (p= 0.009).
- En situation “visuelle surprise inconnue”, les oiseaux dressent plus leur crête lors de l’exposition au stimulus (37%) qu’en contrôle (21%) (p=0.012).
- Il y a un effet de l’individu dans toutes les conditions

Il semble donc que les oiseaux soient plus réactifs à la modalité visuelle qu’à la modalité auditive.

Sur la condition “peur familière”, les oiseaux dressent leur crête et l’aplatissent moins quand ils sont exposés au stimulus effrayant. Ils dressent également plus leur crête quand ils sont surpris par un élément inconnu.

Chez les huppes, la crête se dresse davantage lorsque l’oiseau perçoit la présence d’une menace (Ruiz-Rodríguez et al.,2017). Les auteurs ont suggéré que cela pourrait être une façon d’intimider le prédateur. En revanche, l’étude de Bertin et al. (2018) révèle que chez les perroquets, les plumes sont davantage ébouriffées lors des activités de détente et des

interactions sociales positives, ce qui semble plutôt différer des calopsittes, dont la crête semble plus aplatie dans un contexte contrôle.

Par ailleurs, la présence d'un effet de l'individu dans toutes les conditions suggère que les oiseaux diffèrent entre eux dans les variations de mouvements de crête.

Subtilité du codage de la position de la crête

Les variations de la position de la crête sont sans doute beaucoup plus sensibles que ce que nous avons pu observer.

Premièrement, de multiples raisons peuvent déclencher des mouvements de crête, et toutes ces raisons ne sont pas contrôlables. Des bruits extérieurs notamment (tels que celui de l'aspirateur, ou d'un oiseau qui chante dans la pièce à côté) ont pu influencer le comportement des oiseaux, et engendrer des résultats moins tranchés. De plus, l'implantation des plumes est un peu différente en fonction des individus et cette disposition change très facilement (par exemple il suffit que deux oiseaux se battent ou d'une nouvelle mue pour que l'orientation des plumes change légèrement). C'est donc une analyse qui demande particulièrement d'attention et de précision. Enfin, notre découpage (« aplatie », « intermédiaire », « dressée ») pourrait par la suite être plus détaillé : s'il était intéressant de poser certaines bases en partant de ces trois positions, il est probable que ces mouvements de crête se déclinent en davantage de nuances qu'il serait intéressant d'explorer.

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Thème : étude de la sensibilité musicale chez les oiseaux – soutenance : novembre 2019
Mise en œuvre du projet, mise en place de protocoles, manipulation d'oiseaux, travail d'équipe, encadrement de stagiaires, création de grilles comportementales.

Nov 2016 - Jan 2019 : enseignante, ***Universités Paris Nanterre*** et ***Paris 13 Villetaneuse***
Enseignement de cours magistraux et travaux dirigés (éthologie, neurosciences, psychologie, biologie)
Animation, adaptation au public, conception de dispositifs pédagogiques, transmission des connaissances.

Avr 2015 - Mai 2015 puis **Janv 2016 - Juil 2016**, **stagiaire, *Université Paris Nanterre (LECD)***
Thème : différentes formes d'empathie chez la perruche calopsitte.
Autonomie, application de protocoles, manipulation d'oiseaux.

Vie associative et engagements

Depuis sept 2018 : représentante des doctorantes du laboratoire, *Université Paris Nanterre (LECD)*
Défense des intérêts des doctorantes du laboratoire lors de réunions d'équipes au sein de l'université

Depuis oct 2018 : **co-fondatrice et trésorière**, ***Association des Doctorant.e.s de Nanterre (ADN)***
Gestion de projet, travail et reunions d'équipe, recherche de financements et de soutien, promotion et communication autour de l'association

Depuis avr 2017 : membre du comité éthique de l'UFR SPSE, *Université Paris Nanterre*
Evaluation de projets de recherche sur le plan éthique

Depuis oct 2016 : **responsable de la section Littérature, *eMaginarock*** (association depuis mars 2018)
Encadrement d'une vingtaine de chroniqueurs, mise en place d'objectifs et de projets (couverture de salons, développement de partenariats littéraires…)

Formation

Depuis sept 2016, *Université Paris Nanterre (LECD)* : Préparation d'un doctorat en éthologie

2015 – 2016, ***Université Paris Nanterre*** : Master 2 de psychologie cognitive et technologies, neuropsychologie, neurosciences, spécialité éthologie

2014 – 2015, ***Université Paris 13 Villetaneuse*** : Master 1 d'éthologie

2012 – 2013, ***Université Paris Descartes*** : Master 2 de psychologie clinique et psychopathologie

Informations complémentaires

Langues : Anglais (courant), Espagnol (courant), Italien (Intermédiaire), Portugais (Notions)
Informatique : windows, word, open office, power point, excel, R
Centres d'intérêt : Lecture et écriture, oiseaux, voyages, sport

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Activité scientifique

Publications

Le Covec, M., Aimé, C. & Bovet, D. (2019). Combinatory sound object play in cockatiels : a forerunner of music ? Behaviour. 1:23. DOI: 10.1163/1568539X-00003551

Liévin-Bazin, A., Pineaux, M., **Le Covec**, **M**., Gahr, M., Bovet, D. & von Bayern, A. (2019). Food sharing and affiliation: An experimental and longitudinal study in cockatiels (*Nymphicus hollandicus*). Ethology. 215:276-288. 10.1111/eth.12850.

Articles soumis

Le Covec, M., Aimé, C., Tran, U.T.T., Esseily, R. & Bovet, D. Effects of listening to music on behaviour and social interactions in cockatiels (*Nymphicus holladicus*), soumis à *Animal Cognition.*

Le Covec, M., Di Stasi, R., Bouet, L., Watanabe, S. & Bovet, D. Musical preferences, indifference to the consonance / dissonance feature and personality in cockatiels, soumis à *Animal Cognition.*

Le Covec, M., Bouchekioua, Y., Watanabe, S., Izawa, E.-I. & Bovet, D. Musical preferences and influence of music on behaviour in jungle crows, soumis à *Behavioural Processes.*

Le Covec, M., Bobin-Bègue, A., Watanabe, S., Izawa, E.-I. & Bovet, D. Spontaneous tempo production in cockatiels (*Nymphicus hollandicus*) and jungle crows (*Corvus macrorhyncos*): a prerequisite to produce rhythms, soumis à *Animal Cognition*.

Aimé, C., Tran, U.T.T., **Le Covec, M.**, Bovet, D. & Esseily, R. Is music an evolutionary adaptation? Effects of listening to music on social interactions in preschool children, soumis à *Animal Cognition.*

Communications orales

Le Covec, M., Aimé, C., Tran, U., Esseily, R. & Bovet, D. Influences musicales sur le comportement chez les perruches calopsittes. Colloque de la Société Française pour l'Etude du Comportement Animal, Gif sur Yvettes (France), mai 2017.

Liévin-Bazin, A., **Le Covec M.**, Pineaux M., Bovet D. & von Bayern AMP. The role of food-sharing: a comparative study in cockatiels and jackdaws. Workshop "animal communication" Franco-German Symposium, Nanterre (France), décembre 2018. Présenté par A. Liévin-Bazin.

Aimé, C., Tran, U., **Le Covec, M**., Bovet, D. & Esseily, R. A comparative study on evolution of music and prosociality in humans and cockatiels (*Nymphicus hollandicus*). International Congress of Infant Studies, Philadelphie (USA) juillet 2018. Présenté par C. Aimé.

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Activité scientifique (suite)

Posters

Le Covec, M., Boué, L. & Bovet, D. Des oiseaux musiciens ? Exploration de la production sonore et utilisation d'outil chez la perruche calopsitte. Colloque de la Société Française pour l'Etude du Comportement Animal, Rennes (France), juin 2018.

Le Covec, M., Boué, L., Di Stasi, R. & Bovet, D. Individual musical preferences in cockatiels. 2nd international student course in behavioural biology, Villetaneuse (France), septembre 2019.

Di Stasi, R., **Le Covec, M.** & Bovet, D. Musical preferences in cockatiels: consonant or dissonant music? 2nd international student course in behavioural biology, Villetaneuse (France), septembre 2019.

Vulgarisation scientifique

2019 : **intervenante, *Pint of Science***
Présentation orale à but de vulgarisation scientifique - *Des animaux en musique : quand l'intelligence des oiseaux nous éclaire sur les origines de la musique*

2017 et 2018 : ***Declics***, vulgarisation de la recherche scientifique auprès de lycéens

Publications littéraires (nouvelles et textes courts)

Un pont entre les mondes, *In. Frontières,* éditions Parchemins et traverses (2017).

Le manoir aux urnes, *In. Mort(s),* éditions Les Artistes Fous (2016).

Une peau blanche comme la lune et des yeux bleus comme les étoiles, *In. Sombres tombeaux,* Les éditions du 38 (2016).

Le perroquet pour les nuls, *In. Compagnons d'écrivains*, éditions Ikor (2016).

Tu ne tueras point, *In. Malpertuis VII*, éditions Malpertuis (2016).

La femme, *In. Le Vampire des origines,* éditions Lune écarlate (2015).

L'accordeur, éditions Mythologica (2015).

Tous les verres d'absinthe, *In. Les Hésitations d'une Mouche n°73* (2015).

Le collectionneur de plumes, *In Malpertuis VI*, éditions Malpertuis (2015).

L'arbre aux lucioles, *In. Malpertuis V,* éditions Malpertuis (2014).

Le même sang coule dans mes veines, *In. Folie(s)*, éditions Les Artistes Fous (2014).

Sarkophagos, *In. Malpertuis II,* éditions Malpertuis (2010).